The spore record of early land plants from upper Silurian strata in Klinta 1 well, Skåne, Sweden

Kristina Mehlqvist

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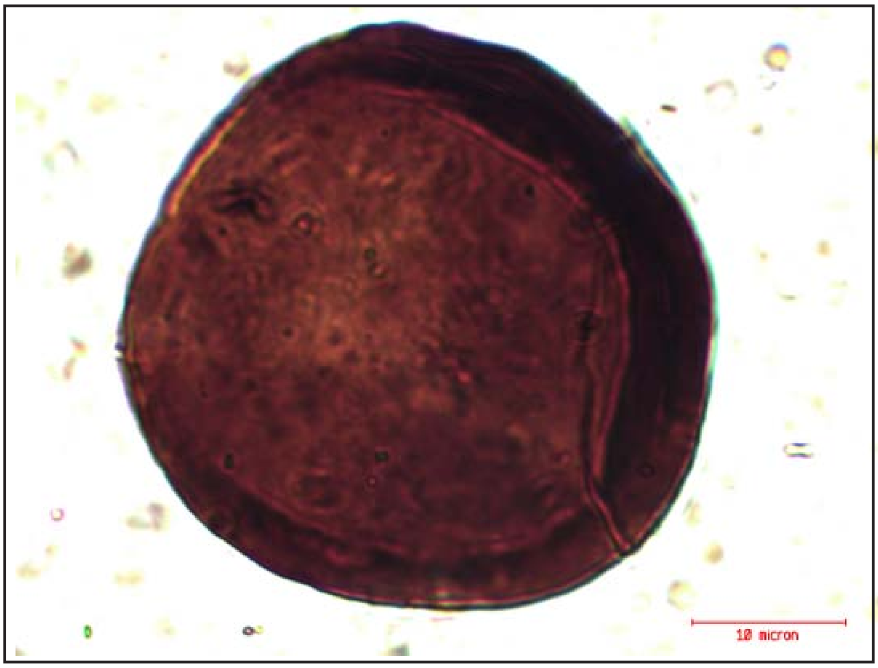

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Master Thesis
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Cover Picture: *Genudnaspora divellomedia.*

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Abstract: Samples from the upper Silurian Öved-Ramsåsa Group, Skåne, Sweden have been investigated palynologically. The sediments are dominated by siliciclastic deposits with minor carbonate units and the palaeoenvironmental setting has been interpreted as a near shore marine ecosystem which grade from open marine shallow subtidal to lagoonal intertidal conditions, offering a prime target for palynological analysis of near shore marine facies. A total of 28 samples were processed palynologically from the drill-core Klinta BH 1 and the terrestrial record is, in this marine setting, represented by spores of early land plants. The study has revealed a well preserved palynological assemblage dominated by spores from land plants. A total of 14 spore species belonging to 11 genera were identified and additionally three taxa were identified to genus level. The high percentage of spores at some levels signifies a near-shore, intertidal environment. Apart from spores, wood remains and marine palynomorphs, such as acritarchs, are present in the palynological assemblages. The relative abundance of spores varies throughout the core, from abundances as high as 100% down to 0% in some samples. A decrease of relative spore abundance is generally met by an increase in marine microfossils such as acritarchs, scolecodonts and chitinozoans. The sediments at the interval 85-93 m in the core, are characterized by a lack of spores and instead a high abundance of wood, which possibly indicates poor conditions of preservation. Palynostratigraphy based on the identified spores indicate that the studied sediments are of a late Ludlowian (Ludfordian) age (420 Ma) based on the presence of the following key-species; *Emphanisporites negelctus*, *Hispanediscus verrucatus*, *Synorisporites* cf. *libycus* and *Apiculiretusispora*? *burgsvikensis*. The spore zonation has subsequently been correlated with the existing biostratigraphical scheme based on conodonts, graptolites and tentaculitids. Spores change in colour with increasing depth of burial and this has shown to be a widely applicable method for thermal maturity determination in hydrocarbon source rocks. This study shows a maturity index of -3 (TAI) and 7 (SCI). Indicating that hydrocarbon presence is potentially possible as the Thermal Alteration Index (TAI) is within the “oil window”.

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Keywords: Silurian, spores, flora, palynology, Klinta 1 drillcore.

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Sporer från tidiga landväxter från översiluriska strata i Klinta borrhål 1, Skåne, Sverige

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Mehlqvist, K., 2009: Sporer från tidiga landväxter från över siluriska strata i Klinta borrhål 1, Skåne, Sverige. Examensarbete 45 högskolepoäng (45 ECTS-poäng) i Geologi, Vt 2009. (*Examensarbeten i Geologi vid Lunds universitet – Berggrundsgeologi, nr. 239*)

Sammanfattning: Prover från Öved-Ramsåsagruppen i Skåne från övre silur har undersökts palynologiskt, främst med avseende på sporer från landväxter. Sedimenten består av karbonater med silisiklastiskt innehåll och paleomiljön har tolkats till ett strandnära marint ekosystem. Detta har graderat från öppen marin, grund-subtidal till lagun eller intertidal miljö, vilket erbjuder en god möjlighet till palynologiska analyser av strandnära marina facies. 28 prover processades palynologiskt från borrkärnan Klinta borrhål 1. Sedimenten är marina, men material från landmiljö är representerat av sporer från tidiga landväxter. Denna studie visar en välbevarad palynologisk association dominerad av sporer från landväxter. Totalt 14 arter tillhörande 11 släkten av sporer identifierades, samt tre taxa som endast bestämdes till släktnivå. Den relativa förekomsten av sporer varierar i kärnan från 100 % ner till 0 % i vissa prover. Där sporförekomsten sjunker ökar generellt förekomsten av marina mikrofossil så som akritarker, skolecodonter och chitinozoer. Interevallet 85– 93 m i kärnan karakteriseras av total avsaknad av sporer och en hög andel ved, vilket tolkas bero på dåliga bevaringsförhållanden. Den höga andelen av sporer på vissa nivåer indikerar en strandnära, intertidal miljö. Förutom sporer från landväxter förekommer också vedrester och marina palynomorfer så som akritarker, chitinozoer och skolecodonter i proverna. Sedimenten har daterats med hjälp av sporerna till sen silur (sen ludlow; ludfordian, ca. 420 miljoner år) med hjälp av följande nyckelarter; *Emphanisporites negelctus*, *Hispanediscus verrucatus, Synorisporites* cf. *libycus* och *Apiculiretusispora*? *burgsvikensis*. Dateringen baserad på sporer har korrelerats med nuvarande biostratigrafisk zonering, i sin tur baserad på conodonter, graptoliter och tentaculiter. Sporer ändrar färg med ökande begravningsdjup och detta har visat sig vara en bra metod för att tolka paleotemperatur och mognad i moderbergarter för kolväten. Denna studie påvisar ett ”Thermal alteration index” (TAI) på –3 och ett ”spore Color index” (SCI) på 7, vilket indikerar att det finns en möjlighet för kolväten att existera eftersom (TAI) är inom ”oljefönstret”.

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Nyckelord: silur, sporer, flora, palynologi, Klinta borrkärna 1.

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1. Introduction

Regarding the evolution of land vegetation, the Silurian period (443 to 416 Mya) is of specific interest. Although, land plants originated in the mid-Ordovician according to evidence from fossil spores, the divergence of the four major living clades: liverworts, hornworts, mosses and vascular plants are believed to have occurred during the late Ordovician and Silurian (Bateman et al. 1998). The first vascular land plant; *Cooksonia*, appeared in the late Silurian (Traverse 1988) and these early floras are regarded to have been cosmopolitan as the sporomorph assemblages from Baltica, Gondwana and Laurasia show large similarities. Generally, the floras also had low diversities.

The Silurian period was characterised by strong environmental changes indicated from positive δ^{13}C and δ^{18}O excursions and three marine extinction-isotopic events are known globally; the earliest Wenlock Ireviken Event, the late Wenlock Mulde Event and the late Ludlow Lau Event (Fig.1) (Jeppsson et al. 1995). Thus, it is of great interest to gain more information about land vegetation during these events. For example, based on a study of the palyonomorph distribution on Gotland (Stricanne et al. 2005) it has been suggested that during the late Ludlow, Lau Event, both marine and terrestrial realms were synchronously affected by climatic changes and that an increase in marine palaeoproductivity couldn't have been the cause of the positive δ^{13}C excursion. In Skåne, the Lau Event is marked by an increase in cyanophytes, extreme δ^{13}C-excursions, cerebroid ooids, and evaporite tracers (Wigforss-Lange 1999; 2007).

The aims of this study is to erect a palynostratigraphy based on spores from land plants for the Lau Event interval, describe and assess the diversity of Silurian spore assemblages on basis of the palynological assemblages from Klinta, Skåne (Sweden). The paleoenvironmental setting of this site represent a near shore marine ecosystem, grading from open marine shallow subtidal to lagoonal intertidal conditions (Wigforss-Lange 2007), offering a prime target for palynological analysis of near shore marine facies. A further aim is to present a correlation of the palynodata with the existing, biostratigraphical schemes of other fossil groups such as conodonts, graptolites and tentaculitids. Another aim was also do determine the thermal alteration index based on the spore colour.

2. Methods

One drillcore, spanning the upper Silurian Öved-Ramsåsa Group in Skåne was sampled, Klinta BH 1 (bore-hole). A total of 28 samples were selected for palynological investigation. The palynological processing was carried out at Global Geolab Ltd., Alberta, Canada. The samples were processed according to standard palynological procedures, first treated with dilute hydrochloric acid (HCl) to remove calcium carbonate, and subsequently macerated by leaving the sample in hydrofluoric acid (HF) of a concentration of 75% over night. The organic residue was sieved through a 20 µm mesh and mounted in epoxy on strew slides. The contents in the samples were grouped in the following categories; spores, acritarchs, fungi, wood, scolecodonts and chitinozoans. One slide /sample was studied and all the palynomorphs per slide were counted using light microscopy and the total content in each slide was registered, reaching between 5 –

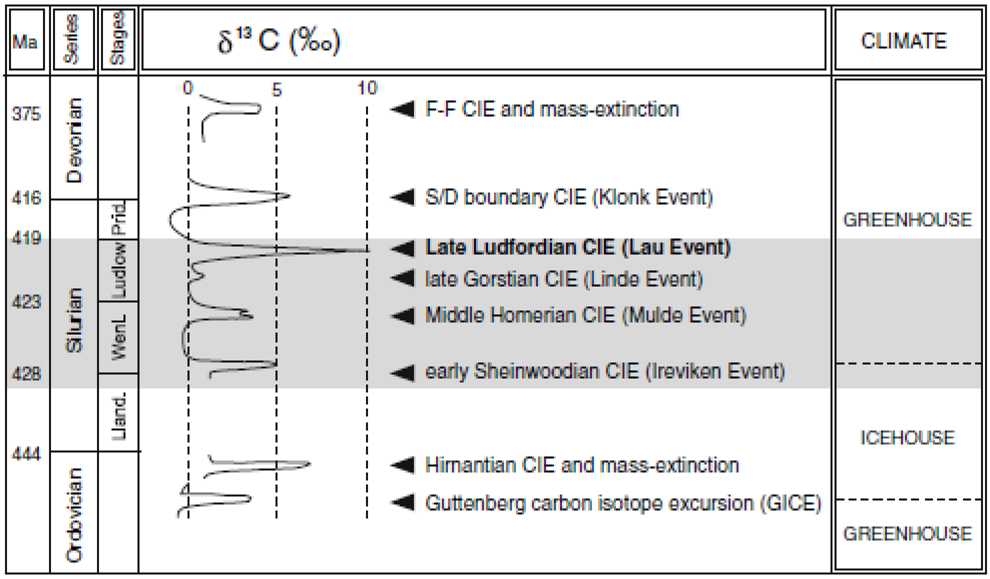

Fig. 1. A carbon isotope curve showing the Palaeozoic events (Eriksson & Calner 2008)

10 000 objects per slide. Subsequently, 150 land plant spores/ sample were studied and identified taxonomically by light microscope of which some were selected for SEM studies. Palynological slides and macerated residues are deposited at the GeoBiosphere Science Centre, Lund University, Sweden and illustrated spores are registered by LO- numbers. The colour of the palynological matter in order to assess the Thermal Alteration Index was registered by visual examination through light microscope in each sample throughout the sequence. The colour scheme of Pearson (1984) has been employed.

3. Geological setting

During the Silurian, Laurentia and Baltica were located in a tropical climate zone on low latitudinal positions south of the equator (Moore et al. 1994). 440 Ma Baltica collided with Avalonia and created a combined landmass. These combined landmasses collided with Laurentia about 425 to 420 Ma and created the supercontinent Laurasia. Based on paleomagnetic data, Laurasia then appeared to have drifted southwards and underwent counter-clockwise rotation at the same time (Cocks & Torsvik 2002).

Parts of Baltica were covered by an epicontinental sea and preserved Silurian deposits have been identified in Norway, mid- and south Sweden, the Baltic Sea, the East Baltic States, Denmark and Poland. In Skåne, the Silurian strata, which reflect a gradual shallowing-up from deepwater graptolitic shales to shallow marine limestones and sandstones, are divided into lower and middle Silurian Rastrites Shale, Cyrtograptus Shale, Colonus Shale and the upper Silurian Öved-Ramsåsa Group (Wigforss-Lange 1999).

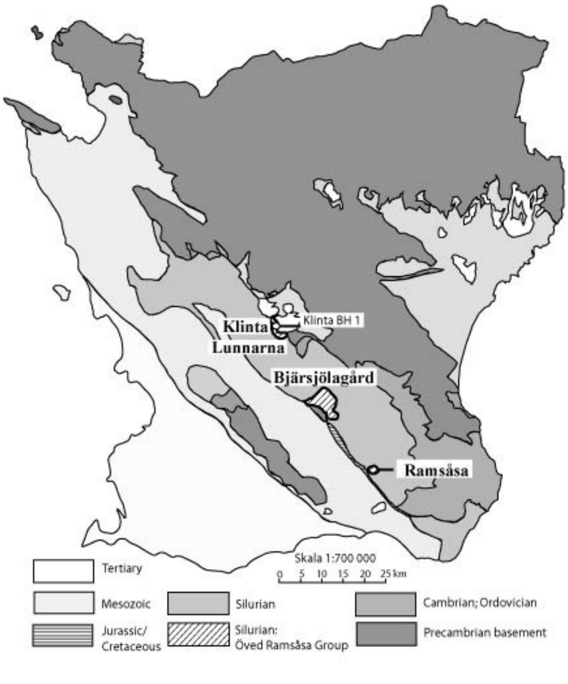

Fig. 2. Map over Skåne, Sweden, showing the drill site of the drill core Klinta BH1 (Courtesy of Jane Wigforss-Lange).

The Öved-Ramsåsa Group is the youngest Palaeozoic strata in Skåne and is of Ludlow (Ludfordian stage) and Pridoli age; based on biostratigraphy of various marine fossil groups (Jeppsson et al. 2006). This group is divided into the Klinta Formation and Öved Sandstone Formation (Jeppsson & Laufeld 1986). The former is subdivided into the Lunnarna, Bjär, Bjärsjö, Bjärsjölagård Members and E3, the latter is subdivided into Eichstädts units E4, E5 and E6. Exposures of the Öved-Ramsåsa Group can be found in Klinta, Lunnarna, Bjärsjölagård and Ramsåsa (Fig. 2). The Group is dominated by mudstones, in places tidally influenced, inter-layered with shallow marine carbonates. These, mainly argillaceous siliciclastic deposits are, in Bjärsjölagård interrupted by a 25 m thick carbonate unit i.e. the Bjärsjölagård Limestone with high abundance of oncoids, corals, crinoids and bryozoans (Wigforss-Lange 1999). The contemporaneous deposits in Klinta (Bjärsjö Member), interpreted as a near shore tidally influenced environment grading from open marine shallow subtidal to lagoonal intertidal conditions, contain cerebroid ooids, and evaporites tracers (Wigforss-Lange 2007). This is followed by a ca 12 m thick sandstone unit (E4) present in both the Klinta area and in the Bjärsjölagård area. The deposits analysed in this study comprise these sequences i.e. the Bjär Member, Bjärsjö Member (corresponding to the Bjärsjölagård Limestone), E3 and E4.

Gotland was during the Silurian, part of a broad epicontinental sea on the south-east rim of Baltica (Wenzel 2000). The sediments consist of ca 450–500 m shallow marine carbonates and marls. The Ludlow of Gotland is divided in to the Hemse Group, the Eke, Burgsvik, Hamra and the Sundre formations (Cherns 1982). The Öved-Ramsåsa Group in Skåne correlates to the Eke beds and the basal part of Burgsvik beds at Gotland (Jeppsson et al. 2006). These deposits show a similar development, the Eke Beds consists mainly of oncoids and the Burgsvik Beds is composed of the Burgsvik Sandstone and the Burgsvik Oolite. The boundary Eke- Burgsvik beds are regarded to correlate with the upper part of the Bjärsjölagård Limestone (Jeppsson et al. 2006).

4. Background

4.1 Silurian paleogeography and climate

During the Silurian, the continents were concentrated to the southern hemisphere while the northern hemisphere was oceanic (Fig. 3; Moore et al. 1994) and epicontinental seas were widespread during this

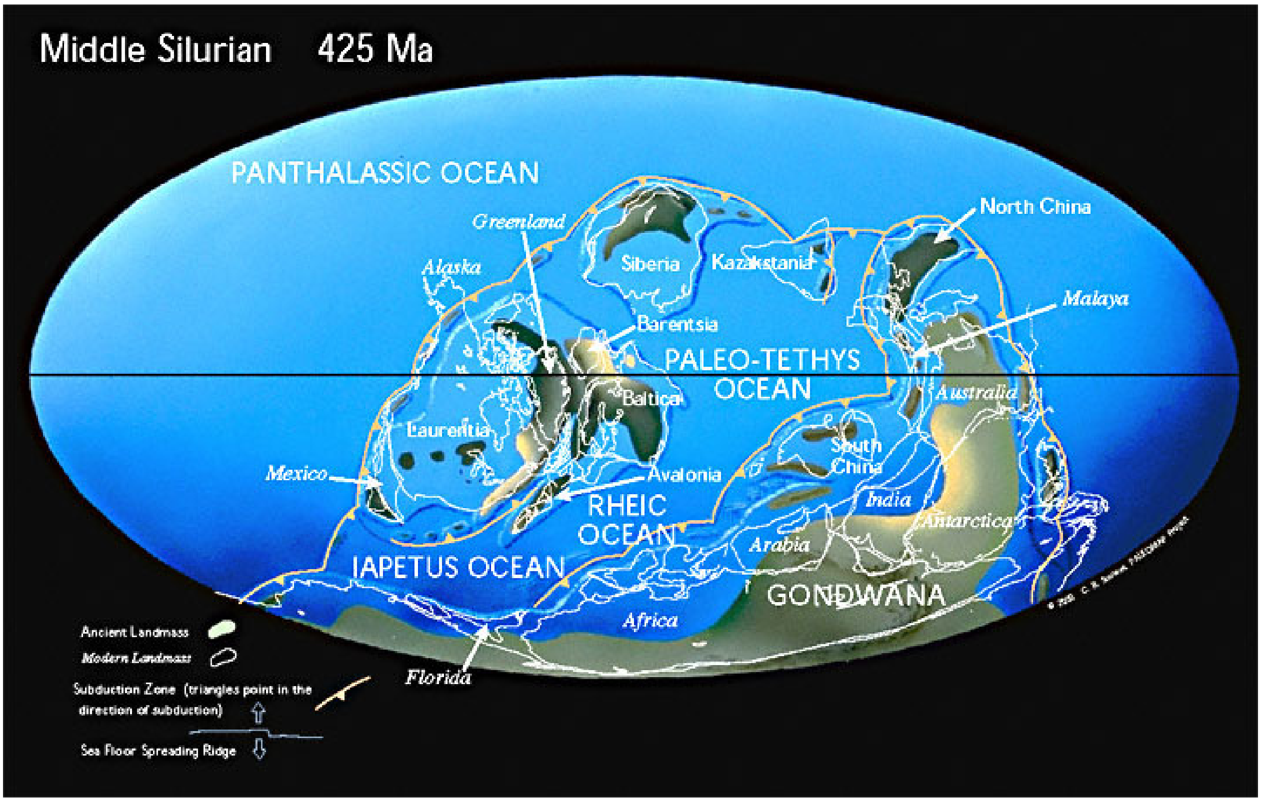

Fig. 3. Paleogeographical map showing the paleocontinents during the middle Silurian (http://www.scotese.com/).

period (Ziegler 1977). Gondwana was the largest Silurian continent and probably made up more than half of the land areas in the world. The super continent included present Africa, South America, Australia, Antarctica, India and some adjacent parts of Asia and Europe (Cocks & Scotese 1991; Fig. 3).

Baltica included northern Europe, southeast Newfoundland, Nova Scotia and coastal areas of New Brunswick and New England. Laurentia contained North America, Greenland, Scotland, northwest Ireland, and Spitsbergen (Ziegler 1977) upper nappes of Norway and western Sweden (Cocks & Scotese 1991; Fig. 3).

The Early Silurian is characterized by global icehouse climate and extensive ice-sheets covered high latitude areas. However, by mid-Silurian, global climate had become much warmer, and a green house phase was initiated, leading to the melting of many large glacial ice sheets. This led to rise in global sea level even though glaciers remained at high latitudes. The paleoequator in Silurian was probably dry in comparison of today's humid equator. Studies have shown an arid belt stretching from 40 N paleolatitude to 40 S paleolatitude indicated by the distribution of evaporates, calcretes and reefs (Ziegler 1977). The distribution of land-plants of this time also indicates a dry equator (Raymond et al. 2006).

During the Silurian several major environmental changes occurred and these changes are evident in positive oxygen and carbon isotope excursions in middle- low-latitude paleo-continents (Stricanne et al. 2005; Munnecke et al. 2003; Lehnert et al. 2006 and references therein).

4.2 Land plants

Land plants originated in the mid-Ordovician based on the presence of fossil spores. The divergence of the four major living clades: liverworts, hornworts, mosses and vascular plants are believed to have occurred during the late Ordovician and Silurian (Bateman et al. 1998). The earliest land plants were embryophytes and evolved from charophycean green algal ancestors. These early land plants probably had bryophyte like anatomy and physiology (Edwards & Wellman 2001, Wellman & Osterloff 2003; Gray 1985). Macrofossils of land plants are rare in Silurian sediments, probably because they lacked fossilizable tissues and their existence is mostly evident by preserved spores. Spores have an exine of sporopollenin that is very resistant to desiccation and they are therefore easily preserved. The sporopolleninous exine protects the protoplasts of spores from desiccation, oxygen, UV- radiation and/or predation. This protective exine was first used by acritarchs and also by bryophyte-like green plants (Traverse 1988). The microfossil record of dispersed spores was first dominated by cryptospores. The spores are called cryptospores because they occur in unusual configurations like in dyads and tetrads (Gray 1985; Richardson 1996b; Steemans 2000; Strother 2000; Fig. 4). Cryptospores include permanent tetrads, dyads and alete monads

(Richardson 1996b). Cryptospores are found around the globe and the assemblages are very similar and suggest that the vegetation was cosmopolitan and consisted of ecological generalists (Steemans et al. 2009). From the mid-Ordovician to the mid-late early Silurian, the land plants are represented by distinctive spore assemblages of obligate tetrahedral spore tetrads, some smooth-walled, others enveloped in a perisporal membrane of sac, minor number of smooth-walled single trilete spores (in the post-Ordovician); cuticle fragments and in the end of early Silurian also tracheid -like tubes (Gray 1985). In Wenlock (early late Silurian) the earliest unequivocal land plant macrofossils occur and are represented by rhyniophytoids. The earliest land plant spores are believed to be either bryophyte-like or simply bryophytes. In the Llandovery (late early Silurian) a major change in the nature of spore assemblages took place over almost the whole globe (Wellman & Grey, 2000). Separated products of dyads (hilate monads) and tetrads (trilete spores) became very abundant in the fossil records (Fig. 4). The origin of trilete spores is according to Wellman & Gray (2000) probably a consequence of the appearance of vascular plants. Little is known about the cryptospore producing plants and Richardson (2007) propose that the cryptospores belong to a group of unknown plants that probably was non-vascular.

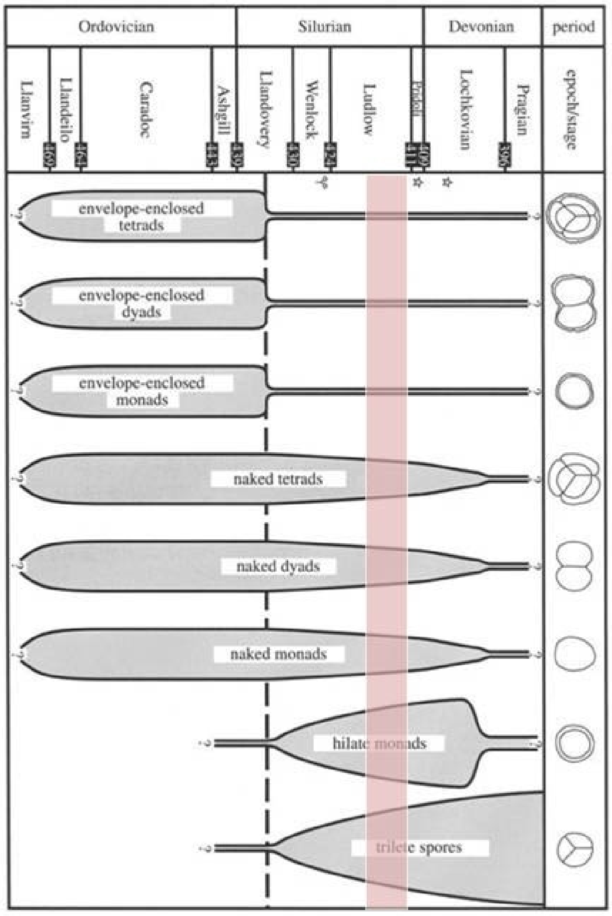

Fig. 4. Stratigraphical range chart for early land plant spore morphotypes. Box indicating the sampled interval in this study (modified from Wellman & Gray 2000).

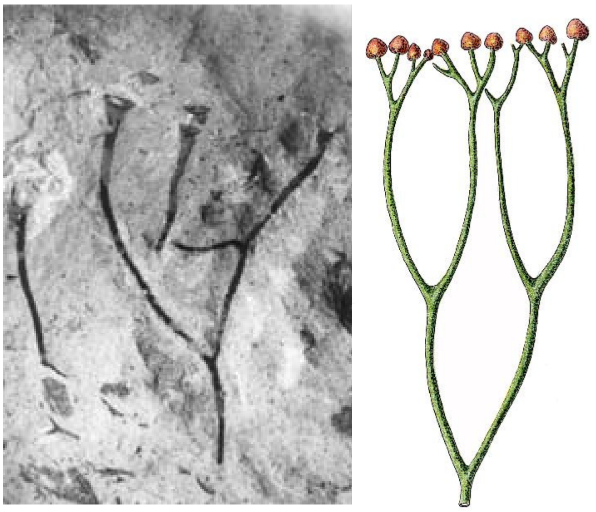

Fig 5. A fossilized *Cooksonia* plant (http://bio.1september.ru/articlef.php?ID=200104806) and a reconstruction (http://bio.1september.ru/articlef.php?ID=200104806).

Dispersed phytodebris (enigmatic dispersed fragments) are often found in sporomorph assemblages and are believed to come from embryophytes and/or fungi. These fragments are known from Ordovician to early Devonian and is probably remains from the early terrestrial flora. The fragments can be cuticles, tubular structures (asepate) and filaments (sepate). Their affinity are controversial but they do, however, derive from non-marine organisms since they have been found in continental deposits and show similarities to extant land plants and fungi (Wellman & Gray 2000).

A study from the Stonehaven Group in Scotland on microfossils shows that the mid- Silurian continental plant assemblage had a low diversity and was cosmopolitan (Wellman 1993a). In the mid-late Silurian, an evolution of land-plants occurred among dispersed spores, cryptospores and the complexity of late Silurian zosterophylls and lycopsids. During this time, new groups of land-plants appeared and global dispersion might have been possible by reproduction via miospores during a short interval of time (Raymond et al. 2006). During the late Silurian, the first vascular plant appeared; *Cooksonia* (Fig. 5), and it was fairly common during this period (Traverse 1988) and this Silurian flora consisted of Lilliputian-seized plants with axes only a few millimetres long (Richardson 2007).

4.3 Land plants and climate

Climate signals in land plants from the Silurian are hard to recognize since they have few or no close relatives today. Spores don't show any climate signals but the distribution can be of relevance (Edwards 1998).

Stomata which is used to determine paleo-CO_2

levels, first appear in the Upper Silurian (Pridoli) and superficially resembles the stomata of today (Edwards 1998).

There is a predominance of rhyniophytes and rhyniopytoids in subtropical, arid and temperate latitudes during the Silurian and this can be explained the ruderal hypothesis. This hypothesis evoke that rhyniophytes and ryniopytoids respond to seasonal aridity and seasonal freezing by slow growth or death. When the conditions change to wetter and warmer then recolonazation occur by spores that been dormant in the soils (Raymond et al. 2006).

The late Silurian land-plants are believed to have been sensitive to differences in equatorial climate and non-equatorial climate but less sensitive to differences in subtropical climate and temperate climate (Raymond et al. 2006). Many of the early Silurian occurrences of cryptospores are from high latitudes (Gray et al. 1992; Edwards 1998) in areas associated with ice caps for at least some of this time. The cryptospore producing plants are therefore believed to be little affected by climate changes associated with glaciations and could invade previously glaciated areas very fast (Richardson 1996b; Edwards 1998).

In a paleo-climate simulation by Moore et al. (1994) the results show that the early Silurian land plants probably grew in a humid coastal paleoenvironment. This indicates that the relative humidity was a more important factor than precipitation-evaporation. Relative humidity maps show that plants grew in tropic areas around large bodies of water (Moore et al 1994).

4.4 Comparison between floras

Records of early sporomorphs and plant macrofossils have mostly been found in Baltica and Avalonia (Britain, Scandinavia and Europe) but also from Laurasia (USA) and Gondwana (North Africa and South America) (Burgess & Richardson 1991) and according to Wellman & Gray (2000), the composition of spore assemblages from these paleocontinents are similar. Findings from Shropshire in England in sediments of Wenlock age suggest that nematophytalean plants and possible nematophytalean (non vascular plants), tube-bearing plants were widespread at this time (Burgess & Richardson 1991). In a study of the palynoflora of Gotland made by Hagström (1997), comparisons between contemporary microfloras on other palaeocontinents are presented. The assemblage from the Ludfordian Burgsvik Beds of Gotland are compared to coeval assemblages from North America, Britain and North Africa. The study reveals great similarities between the assemblages but spores characteristic for the Ludfordian period was not present in the Gotland material which may indicate a separation of the Gotland flora from other floras on surrounding land areas (Hagström 1997). Comparisons between an assemblage from Midland Valley (Scotland) made by Wellman and Richardson (1993) shows similarities to coeval assemblages (early Wenlock) from southern Britain, North America, North Africa and elsewhere. They conclude that the flora is well established, abundant and geographically widespread and also cosmopolitan. However the flora had a very low diversity and suggests that the vegetation comprised few forms (Wellman & Richardson 1993).

In the late Silurian, fossil spores start to display different morphological novelties in sculpture patterns and laesurae. The spore assemblages also start to show a lesser uniformity; the assemblage's from North America is distinct from assemblages from Gotland and this suggests a beginning of biogeographical differentiation (Gray 1985).

4.5 Thermal alteration index

Organic microfossils change in colour with increasing depth of burial, the deeper the darker, and these changes have shown to be widely applicable for thermal maturity determination in hydrocarbon source rocks (Traverse 2007) and reveals the palaeotemperatures of the sedimentary rocks hosting the microfossils. The palaeotemperature values may be due to the thickness of the overburden but may also be associated with igneous and tectonic activity.

This, so called Thermal Alteration Index (TAI) is, however, different for different compounds and different fossil groups can not be characterized using the same scales. While dinoflagellates and acritarchs start at a transparent level, spores are generally light amber coloured also in immature sediments, (Vajda pers. com.). Spores consist of sporopollenin, which is a unique compound, consisting of biopolymers, mainly containing long chain fatty acids, certain aminoacids and phenols (Guilford et al 1988). Exines in spores of modern and fresh plants have a pale yellowish colour in transmitted light. When the exines are heated like in deep burial processes the colour intensifies from yellow, to orange, to brown, to dark brown and finally to black (Traverse 2007).

In Pearson (1984) a 10 graded colour-scale was presented based on colour alteration of spores, this has subsequently been refined and reproduced in Traverse (2007). There is also a spore colour index (SCI) and a Thermal Alteration Scale (TAS) that is used when determining source rock maturation (Traverse 2007).

5. Results

5.1 Stratigraphy

The results from this study reveal a rich and well preserved palynological assemblage, highly dominated by spores and wood remains from land plants (Fig. 5). 14 spore species were indentified belonging to 11 genera of which *Emphanisporites neglectus*, *Synorisporites* cf. *libycu*s and *Apiculiretusispora* ? *burgsvikensis* and *Hispanediscus verrucatus* are late Silurian key-species. Most abundant is the species *Gneudnaspora plicata*, followed by *Gneunaspora divellome-*

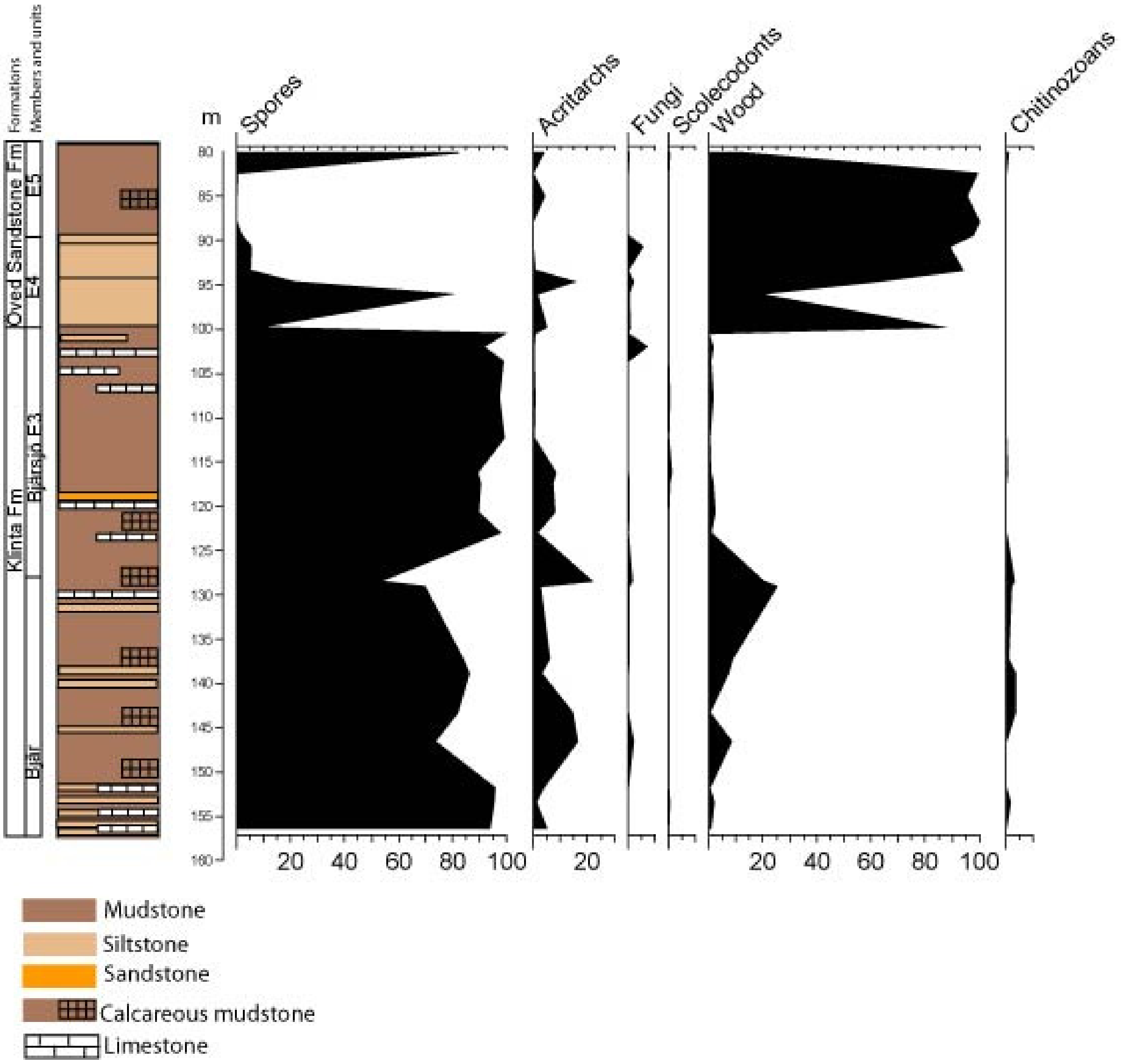

Fig. 6. Relative abundance diagram over palynological groups found in the samples.

dia. There is also a high abundance of *Dyadospora*, especially *D. murusdensa* (Figs. 7–10); Appendix 1 and 2.

According to spore stratigraphy created by Richardson (1996b) the spore assemblages of this study belong to the top of miospore subphase 4B and the base of 5A and is of late Ludfordian age (Fig. 7). Phase 5 is the apiculate-retusoid miospore phase and is characterized by the appearance of *Apiculiretusispora* (evenly granulate to apiculate miospores). In this study this is represented by *Apiculiretusipora ? burgsvikensis* (Fig. 9).

According to spore zonations from the Old Red Sandstone continent (Richardson and McGregor 1986), the assemblage of this study belongs to their Zone 4, the *Synorisporites libycus- ?Lophozonotriletes poecilomorphus* Assemblage Zone. This zone has been dated to Gorstian– Ludfordian age. In the Skåne assemblage of this study the following key–species of this zone are represented; *Synorisporites* cf. *libycus*, *Empahnisporites neglectus* and *Hispanaediscus verrucatus* (Figs. 7-9).

5.2 Palynofacies

The results from this study reveal rich and well preserved palynological assemblages, highly dominated by spores and wood remains from land plants. Other groups present in the palynological residue in low numbers comprise marine microfossils such as acritarchs, chitinozoans and scolecodont elements, further fungal spores prevail in low numbers. Cuticle sheets, tubular structures and net-like structures were

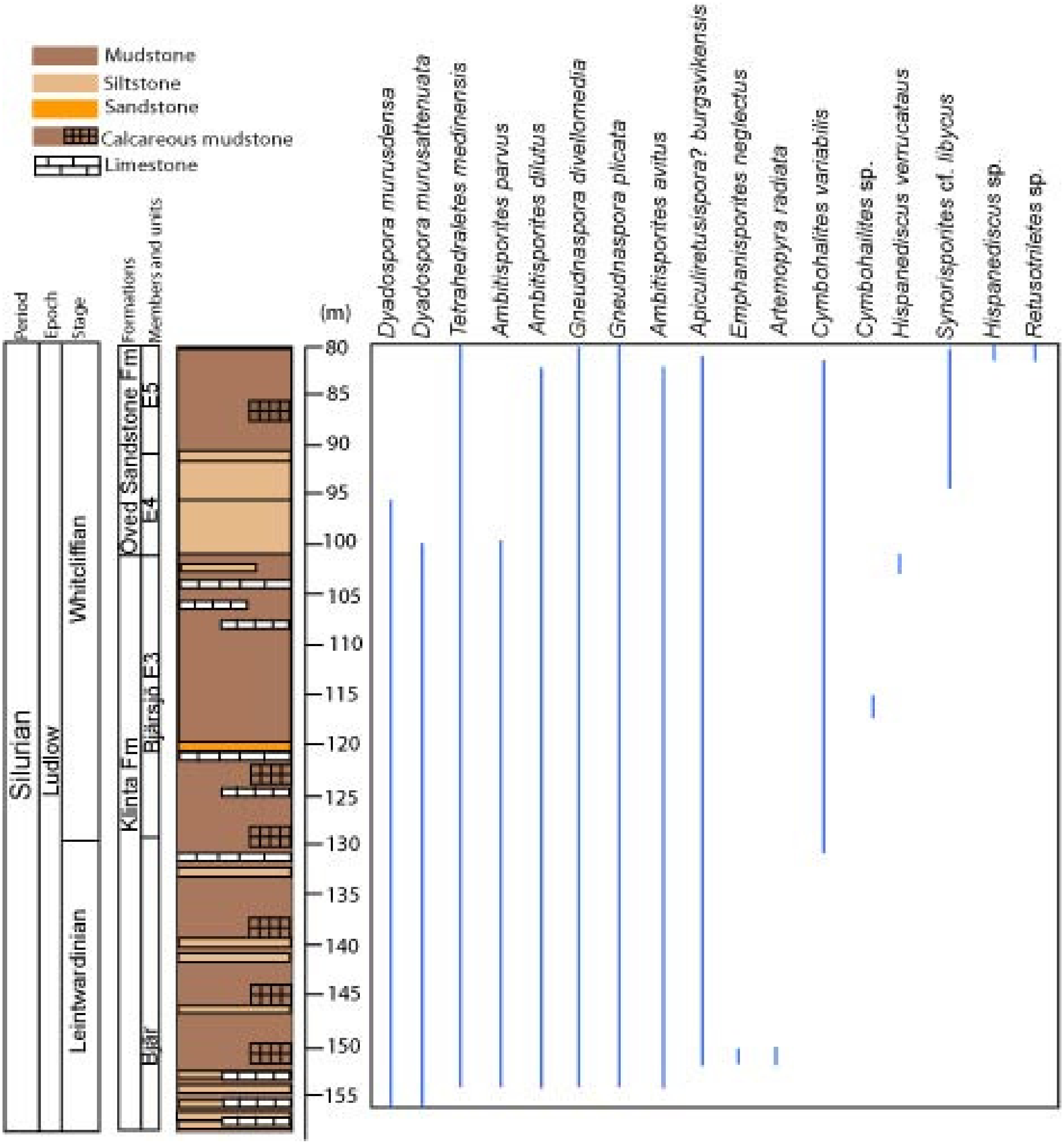

Fig. 7. Range chart showing the different spore species ranges in the samples.

also found in the samples.

In Fig. 6 the relative percentage of the different groups identified in the samples is presented. There is a total dominance of spores from land plants from the base of the sampled core and up to 95 m, where a massive decrease in spores is accompanied with an increase in wood remains. The relative abundance of acritarchs and wood remains shows an inverse relationship to the abundance of land plant spores. In the topmost part of the studied interval, the spores dominate again.

The basal samples (156.37–151.76 m) (Fig. 7 & Appendix 3) are dominated by cryptospores, mainly *Dyadospora murusattenuata D. murusdensa*, *Gneudnaspora plicata* and *G. divellomedia* but specimens of *Tetrahedraletes medinensis* are also present together with the only occurrence of *Artemopyra radiata*. The identified miospores include *Ambitisporites avitus*, *A. dilutus*, *A. parvus*, *Apiculiretusispora* ? *burgsvikensis* and the only occurrence of *Emphanisporites neglectus*.

The lowermost sample (156.37 m) lacks miospores. In this interval there is also indications of marine influences such as occurrences of acritarchs and chitinozoans.

In samples 143.33–138.83 m there is also a dominance of cryptospores. Especially *Gneudnaspora plicata* and *Gneudnaspora divellomedia*, representatives of *Tetrahedraletes medinensis*, are also present. The miospores are represented by *Ambitisporites avitus*, *A. dilutus* and *A. parvus*. There is a major increase in acritarchs in this interval and also a relatively high occurrence of chitinozoans.

In samples from the interval 122.96–116.28 m, the cryptospores dominate and the most commonly occurring species are *Dyadospora murusattenuata*, *Dyadospora murusdensa*, *Gneudnaspora plicata*. Other cryptospores occurring are *Cymbohilates* sp., *Gneudnaspora divellomedia*. *Tetrahedraletes medinensis* and *Cymbohilates variabilis*. Miospores present in lower numbers include *Ambitisporites avitus*, *A. dilutus*, *A. parvus* and *Apiculiretusispora* ? *burgsvikensis*. Several peaks of acritarchs and occurrence of chitinozoans in this interval can be seen in the relative abundance diagram (Fig. 6).

In samples covering the cored interval 112.28–107.71 m, the relative abundance of miospores increases but there is still a dominance of cryptospores. The dominating cryptospores in this interval are *Gneudnaspora plicata* and *Gneudnaspora divellomedia*. *Dyadospora murusattenuata*, *Dyadospora murusdensa* and *Tetrahedraletes medinensis* prevail in lower number. The miospores are represented by *Ambitisporites avitus* and *A. dilutus*. Acritarchs and a small number of scolecodonts are present in this interval.

In the samples from the interval 103.58–101.95 m, the relative abundance of miospores increases to even higher levels, however cryptospores are still dominating and the most prominent species are *Gneudnaspora plicata*, *Gneudnaspora divellomedia* and *Dyadospora murusdensa*. *Cymbohilates variabilis*, *Dyadospora murusattenuata*, *Hispanediscus verrucatus* (only present in one sample) and *Tetrahedraletes medinensis* is also present among the cryptospores. The miospores are dominated by *Ambitisporites avitus*. *A. dilutus* and *Retusotriletes* sp. are also present. No marine organisms are present in this interval.

In the samples from the topmost part of the studied sequence (100.45–80.12 m), the miospore abundance increases further and reaches it's highest level in sample 80.12 m (32%). However, the cryptospores are still dominating, represented by the species *Gneudnaspora plicata* and *Gneudnaspora divellomedia*. *Dyadospora murusdensa*, *Dyadospora murusattenuata*, *Tetrahedraletes medinensis* and *Hispanaediscus* sp. are prevailing in lower numbers. The miospores are strongly dominated by *Ambitisporites avitus*. This interval is further characterized by the first appearance of the key -species *Synorisporites* cf. *libycus* which is present in sample 96.02 m and 80.12 m. Other miospores present are *Ambitisporites dilutus*, *A. parvus* and *Apiculiretusispora* ? *burgsvikensis*. In the topmost sample (80.12 m) there is also a presence of regulated fungal spores (8%). In this interval there is also some occurrences of acritarchs in the lower part and in the uppermost samples of the interval.

The general trend shows a distinct increase of miospores in the topmost part of the investigated section from lacking in the lowermost sample (156.37 m) to an abundance of 32 % in the top most sample (80.12 m).

5.2 Thermal alteration index

The Thermal Alteration Index has been determined to -3 (TAI) and 7 (SCI), indicating that hydrocarbon presence is potentially possible as the Thermal Alteration Index (TAI) is within the “oil window”. This means that the sediments are sufficiently mature to produce hydrocarbons (main phase of liquid petroleum generation).

5.3 Systematic palynology

The presented upper Silurian spores from central Skåne are listed according to the turmal system originally developed for the classification of spores and pollen by Potonié (1893). The system is expanded to include cryptospores (Richardson et al. 1984, Richardson 1988, Richardson & Edwards 1998, Strother 1991). The dimensions are given with the average size in brackets and the minimum and maximum at the flanks. Specimen co-ordinates were obtained by an England finder (E.F.). Figured specimens are stored at the Department of Geology at the University of Lund, Sweden.

Systematic descriptions

Anteturma Cryptosporites; Turma Tetrasporites; Genus *Tetrahetdraletes* (Strother & Traverse) Wellman & Richardson 1993

Type species.– *Tetrahedraletes medinensis* Strother & Traverse 1979

Tetrahedraletes medinensis (Strother & Traverse) Wellman & Richardson 1993

Fig. 8 K–L; Fig. 10F.

Dimensions.– Tetrads 37 (51) 64 µm, measured on 10 specimens.
Description.– Permanent laevigate obligate tetrahedral tetrads. Are preserved in different compressional forms. The contact area between the spores are thickened.
Comments.– The species is very common occurring in most of the samples in BH1; 1, 9, 11, 12, 13, 14, 15, 16, 17, 19, 23, 24, 26, 27, 28.
Range.– The species is common all over the world and

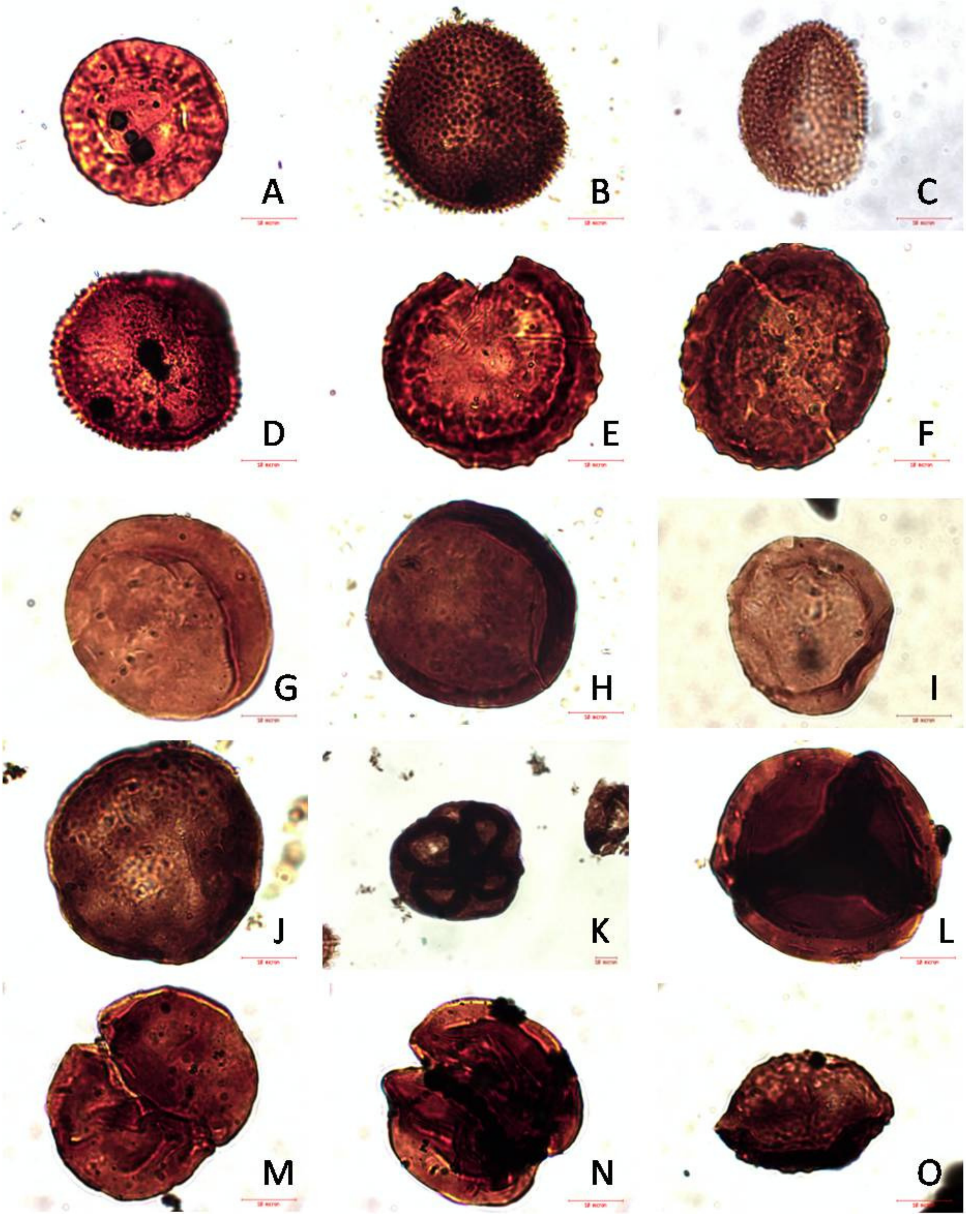

Figure 8. **A**, *Artemopyra radiata* Strother 1991. **B, D** *Cymbohilates variabilis* Richardson 1996a. **C**, *Cymbohilates sp.* **E,** *Hispanaediscus verrucatus* (Cramer) Burgess & Richardson 1991. **F**, *Hispanaediscus sp.* **G- H**, *Gneudnaspora divellomedia* (Chibrickova) Balme 1988 **I**, *Gneudnaspora plicata* Burgess & Richardson 1991. **J**, *Gneudnaspora* sp. **K-L**, *Tetrahedraletes medinensis* (Strother & Traverse) Wellman & Richardson 1993. **M**, *Dyadospora murusdensa* (Strother & Traverse) Burgess & Richardson 1991. **N**, *Dyadospora murusattenuata* (Strother & Traverse 1979) Burgess & Richardson 1991. **O**, Regulated fungal spore.

Red scale bar is 10 µm.

ranges from late Caradocian (Richardson 1988) to Early Devonian (Wellman 1993b).

Genus *Artemopyra* Burgess & Richardson 1991

Type species.– *Arttemopyra brevicosta* Burgess & Richardson 1991.

Artemopyra radiata Strother 1991

Fig. 8A.

Dimensions.– 30 µm, measured on one specimen.
Description.– Hilate cryptospore with a circular amb. Proximal hilum ornamented with radially running ribs from the thickened equatorial ring.
Comments.– Only one specimen was found, in sample 26.

Turma Dyadosporites; Subturma Eudyadosporites: Genus *Dyadospora* Strother & Traverse 1979

Type species.– Dyadospora murusattenutata Strother & Traverse 1979

Dyadospora murusattenuata (Strother & Traverse 1979) Burgess & Richardson 1991

Fig. 8N.

Dimensions.– 29 (39) 52 µm, measured on 10 specimens.
Description.– Dyads, circular to sub circular in equatorial view. Individual spores are distally convex with the crassitude at the contact area between the two spores. Laevigate distal exine, spore often folded.
Comparison.– D. murusattenuata and *D. murusdensa* have very similar morphologies. *D. murusattenuata* is characterised by a thinner folded wall than *murusdensa* (Burgess & Richardson 1991). Distinguish between the two species can be complex.
Range.– From Ashgillian (Vavrdova 1989) to Early Devonian (Wellman 1993b).
Stratigraphic occurrence; BH1, samples 11, 13, 15,16, 19, 23, 26, 27, 28.

Dyadospora murusdensa (Strother & Traverse) Burgess & Richardson 1991

Fig. 8M.

Dimensions.– 30 (38) 51 µm, measured on 10 specimens.
Description.– Dyads, circular to sub circular in equatorial view. Individual spores are distally convex with the crassitude at the contact area between the two spores. Laevigate exine and usually without folds. The spores are often loosely attached.
Comparison.– D. murusdensa have a thicker folded wall than *D. murusattenuata.*
Range.– From Ashgillian (Vavrdova 1989) to Early Devonian (Wellman 1993b).
Stratigraphic occurrence.– BH1, samples 9, 11, 12, 13, 14, 15, 16, 17, 19, 23, 24, 26, 27, 28.

Turma Monocryptosporites; Genus *Cymbohilates* Richardson 1996a

Type species.– Cymbohilates horridus Richardson 1996a

cf. *Cymbohilates variabilis* Richardson 1996a

Fig. 8B–D.

Dimensions.– 30 (36) 47 µm, measured on 3 specimens.
Description.– Proximally hilate cryptosopre with a circular to subcircular amb. Sculptured with evenly distributed spines. Pointed apices.
Stratigraphic occurrence.– BH1, samples 13 and 19.

Cymbohilates sp.

Fig. 8C.

Dimensions.– 25–30 µm, measured on 2 specimens.
Description.– Oval shape with subcirucular amb. Laevigate hilum and distal surface sculptured with spines.
Remarks.– The spores fit the description of the Genus *Cymbohilates* but couldn't be assigned to a species.
Comparison.– Smaller than *Cymbohilates variabilis* and have a different shape, more oval than *C. variabilis*. Looks very similar to the spores described in Hagström (1997) which also were designed to *Cymbohilates* sp.
Stratigraphic occurrence.– BH1, samples 16 and 17.

Genus *Hispanaediscus* (Cramer) Burgess & Richardson 1991

Type species.– Hispanaediscus verrucatus (Cramer) Burgess & Richardson 1991

Hispanaediscus verrucatus (Cramer) Burgess & Richardson 1991

Fig. 8E.

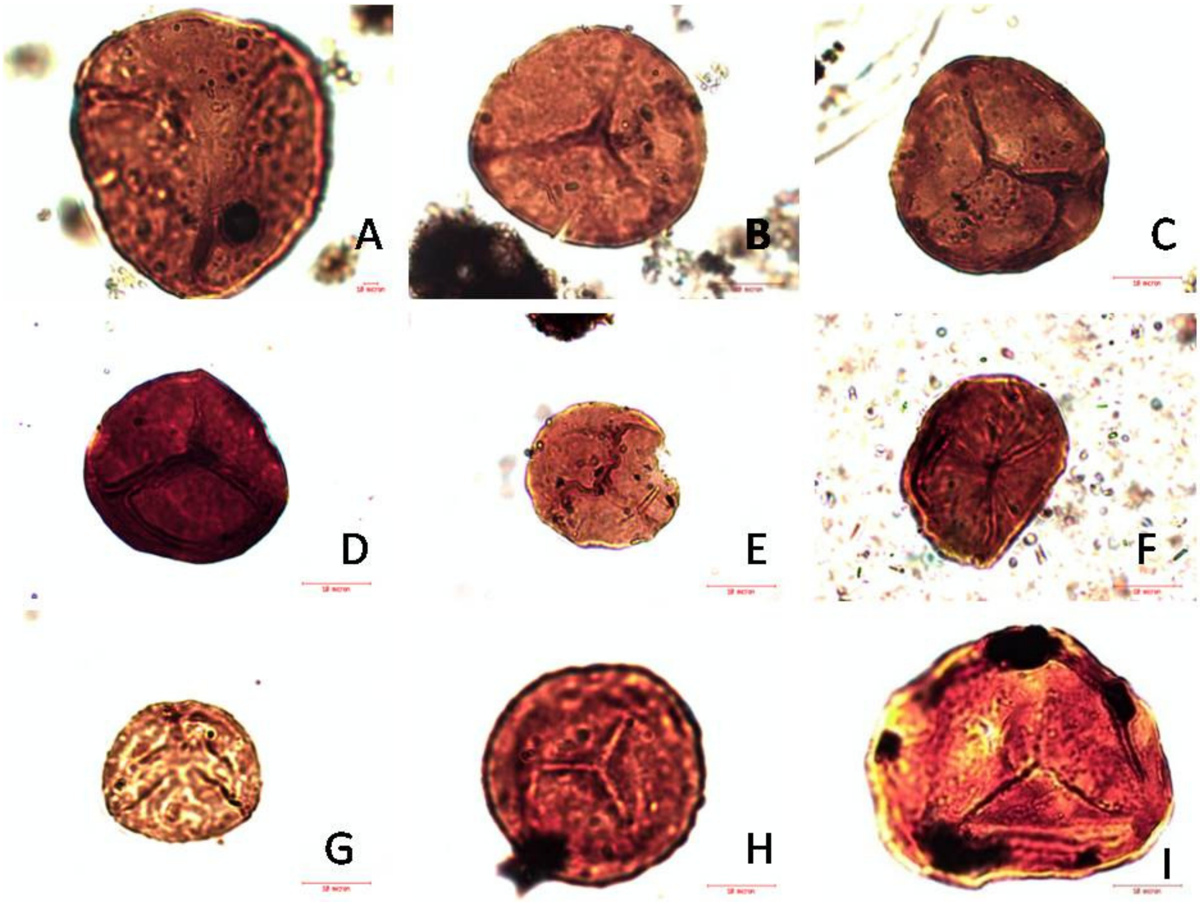

Figure 9. **A-B**, *Ambitisporites dilutus* (Hoffmeister) Richardson & Lister 1969. **C-D**, *Ambitisporites avitus* Hoffmeister 1959. **E**, *Ambitisporites parvus* Burgess & Richardson 1995. **F**, *Emphanisporites neglectus* Vigran 1964. **G**, *Synorisporties cf. libycus* Richardson & Ioannides 1973. **H**, *Retusotriletes* sp. **I,** *Apiculiretusispora ? burgsvikensis* Hagström 1997.

Red scale bar is 10 µm.

Dimensions.– 32 (36) 41 µm, measured on 4 specimens.
Description.– Alete proximal hilate monad with subcircular amb. The hilum is surrounded by an equatorial to subequatorial crassitude. The hilum can be laevigate with muri. Distal face ornamented with verrucae or muri.
Stratigraphical importance.– Hispanaediscus verrucatus is a late Silurian key-species and is a characteristic species of the *Synroisporites libycus*- ? *Lophonzonotriletes poecilomorphus* Assemblage Zone and ranges from mid Homoerian to Downtonian. (Richardson & McGregor 1986).
Stratigraphic occurrence.– BH1, sample 13.

Hispanediscus sp.

Fig. 8F.

Dimensions.– 37 µm, measured on 1 specimen.
Description.– Sub circular to circular amb. Verrucate ornamentation.
Comparison.– Larger distance between grana than in *H. verrucatus.*
Comments.– Very rare, only one specimen was found.
Stratigraphic occurrence.– BH1, sample 1.

Genus *Gneudnaspora* (Chibrikova) Balme 1988 emend. 1991. *Laevolancis* – Burgess & Richardson, p.606.

Type species.– Gneudnaspora kernickii (Chibrickova) Balme 1988

Genudnaspora divellomedia (Chibrickova) Balme 1988

Fig. 8G–H, J; Fig. 10B–C, E.

Dimensions.– 31 (35) 39 µm, measured on 10 specimens.
Description.– Alete proximally hilate monads with circular to oval amb. Laevigate exine with an equatorial to subequatorial crassitude surrounding the proximal hilum. The hilum is flattened to concave in equatorial view but may be folded or ruptured. Can be preserved loosely attached in dyads but are mostly found as single grains.
Comparison.– G. divellomeda and *plicata* have very similar morphologies and can be difficult to separate. *Divellomedia* is characterised by a thicker unfolded wall (Burgess & Richardson 1991). However, the structures of folded or unfolded walls may depend on the state of preservation.
Range.– From Wenlockian (Burgess & Richardson 1991) to Frasnian (Balme 1988).
Stratigraphic occurrence.– BH1, samples 1, 9, 11, 12, 13, 14, 15, 16, 17, 19, 23, 24, 26, 27, 28.

Gneudnaspora plicata Burgess & Richardson 1991

Fig. 8I.

Dimensions.– 28 (33) 41 µm, measured on 10 specimens.
Description.– Can be found in dyads but are often found as separate grains. Amb sub–circular to circular. Crassitude equatorial to subequatorial. The proximal hilum is laevigate, often concave and folded.
Comparison.– G. divellomedia and *G. plicata* are very similar and problematic to distinguish from each other. *G. plicata* tends to be more wrinkled/folded and also have a more yellowish colour than the *G. divellomedia* which often are darker brown in the samples. *G. divellomedia* is also larger than *plicata*.
Range.– From Wenlockian (Burgess & Richardson 1991) to Frasnian (Balme 1988).
Stratigraphic occurrence.– BH1, samples 1, 9, 11, 12, 13, 14, 15, 16, 17, 19, 23, 24, 26, 27, 28.

Anteturma Sporites; Turma Triletes; Subturma Zonotriletes; Infraturma Crassitii; Genus *Ambitisporites* Hoffmeister 1959

Type species.– Ambitisporites avitus Hoffmeister 1959.

Ambitisporites avitus Hoffmeister 1959

Fig. 9C–D & 10A.

Dimensions.– 27 (33) 37 µm measured on 10 specimens.
Description.– Subcircular to roundly triangular in proximal view. Equatorial crassitude. Leavigate to faintly granular ornamentation.
Remarks.– A. avitus is separated from the similar species *A. dilutus* from its larger diameter and thicker crassitude but both species may intergrade (Hoffmeister 1959). Steemans et al. (1996) created a morphon with *A. avitus* and *A. dilutus*.
Range.– Distributed around the world (Steemans et al. 1996). Known throughout the Silurian (Richardson & McGregor 1986) could be from the latest Ordovician (Steemans et al. 1996).
Stratigraphic occurrence.– BH1, samples 1, 9, 11, 12, 13, 14, 15, 16, 17, 19, 23, 24, 26.

Ambitisporites dilutus (Hoffmeister) Richardson & Lister 1969

Fig. 9A–B.

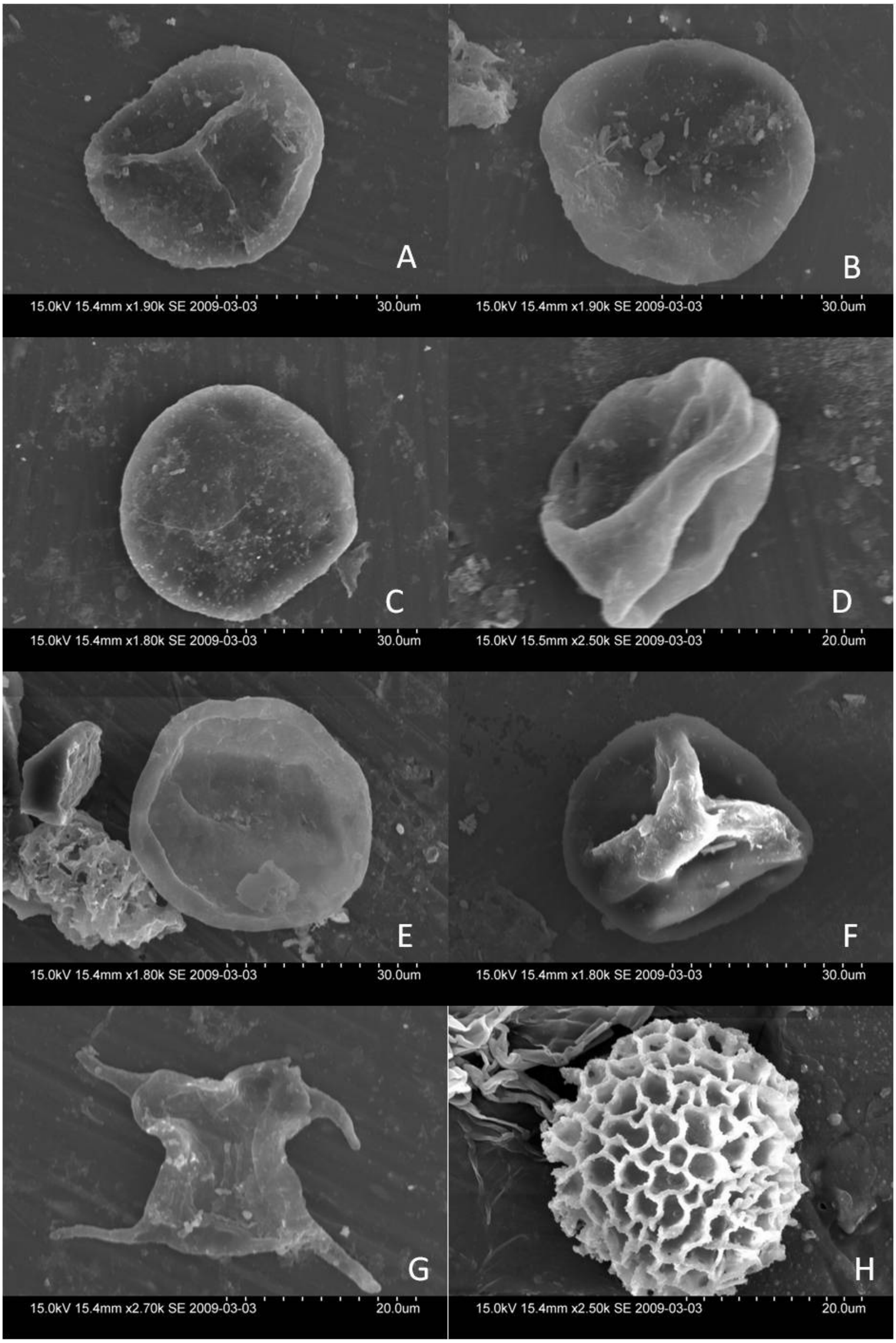

Figure 10. **A**, *Ambitisporites avitus* Hoffmeister 1959. **B-C**, *Gneudnaspora divellomedia* (Chibrickova) Balme 1988. **D**, *Tetrahedraletes medinensis* (Strother & Traverse) Wellman & Richardson 1993. **E**, *Gneudnaspora divellomedia* (Chibrickova) Balme 1988. **F**, *Tetrahedraletes medinensis* (Strother & Traverse) Wellman & Richardson 1993. **G- H**, Acritarchs.

Dimensions.– 27 (38) 58 µm, measured on 10 specimens.
Description.– Subcircular to roundly triangular in proximal view. Equatorial crassitude.
Range.– Distributed around the world (Steemans et al. 1996). Known throughout the Silurian (Richardson & McGregor 1986) could be from the latest Ordovician (Steemans et al. 1996).
Stratigraphic occurrence.– BH1, samples 1, 9, 11, 13, 14, 15, 16, 17, 19, 23, 24, 27.

Ambitisporites parvus Burgess & Richardson 1995

Fig. 9E.

Dimensions.– 22 (24) 28 µm, measured on 6 specimens.
Description.– Small subtriangle trilete miospore with a prominent equatorial crassitude.
Comparison.– Much smaller than *A. avitus. A dilutus* and does not have such a prominent crassitude.
Stratigraphic occurrence.– BH1, samples 11, 19, 23, 24, 26, 27.

Geuns *Synorisporites* Richardson & Lister 1969

Type species.– Synorisporites downtonensis Richardson & Lister 1969.

Synorisporites cf. *libycus* Richardson & Ioannides 1973

Fig. 9G.

Synonymy.– 1995 *Synorisporites* cf. *libycus* Burgess & Richardson Pl. 7, figs. 10–13.

Dimensions.– 19 (19) 20 µm, measured on 3 specimens.
Description.– Sub–triangular amb. Leavigate contact surface. Sculptured verrucae on distal side.
Stratigraphic occurrence.– BH1, samples 1 and 9.
Stratigraphical importance.– Synorisporites cf. *libycus* is a late Silurian key-species and is a characteristic species of the *Synroisporites libycus- ? Lophonzonotriletes poecilomorphus* Assemblage Zone and ranges from Homerian/Gorstian to Downtonian (Richardson & McGregor 1986).

Subturma Azonotriletes; Infraturma Apiculati; Genus *Apiculiretusispora*? Streel 1964

Type species.– Apiculiretusispora brandtii Streel 1964.

Apiculiretusispora? burgsvikensis Hagström 1997

Fig. 9I.

Synonomy.– ?1978 *Retusotriletes* sp. McGregor & Narbonne Pl. 1, fig. 7.

Dimensions.– 39 (42) 45 µm, measured on 3 specimens.
Description.– Subtriangular to subcircular amb. Distal areas covered with densely packed grana. Straight trilete mark sometimes reaching the amb.
Stratigraphical importance.– Apiculiretusispora is a key genus and represents the first appearance of apiculate sculpture. The genus is indicative of the Miospore subphase 5A and indicate late Ludfordian age (Richardson 1996b).
*Stratigraphic occurrence.–*BH1, samples 1, 9, 12, 15, 19, 26.

Infraturma *Laevigati*

Genus *Retusotriletes* Naumova, emend. Richardson, 1965 (not Streel 1964)

Type species.– R. Pychovii Naumova 1953 (lecotype species of Richardson 1965).

Retusotriletes sp.

Fig. 9H.

Dimensions.– 30 µm measured on 1 specimen.
Description.– Circular to sub circular amb. Suturae extending ½ of the radius.
Comments.– Could not be satisfactory determined to species level but fits the description of the *Retusotriletes* genus. Very rare, only one specimen found.
Stratigraphic occurrence.– BH1, sample 13.

Infraturma Murornati Potonié & Kremp 1954

Genus *Emphanisporites* McGregor 1961

Type specis.– Emphanisporites rotatus McGregor 1961.

Emphanisporites neglectus Vigran, 1964

Fig. 9F.

Dimensions.– 30µm, measured on 1 specimen.
Description.– Trilete miospore with a subcircular amb. Contact area is sculptured with indistinct radial ribs.
Comments.– Very rare, only one specimen found in sample 26.

Stratigraphical importance.– *Emphanisporites neglectus* is one of the characteristic species of the *Synroisporites libycus*- ? *Lophonzonotriletes poecilomorphus* Assemblage Zone and indicate Gorstian to Ludfordian age (Richardson & McGregor 1986).

Fungi

Rugulated fungal spore

Fig. 8O.

Synonymy.– 1985 "Rugulately ornamented spore" Sherwood-Pike & Gray (1985), figs. 6N–O, 7H.

Dimensions.– 30–40 µm, measured on 2 specimens.
Description.– Oval to reniform shape, regulate ornamentation. Sometimes with snouts in the ends.
Stratigraphic occurrence.– BH1, sample 1.

6. Discussion

6.1 Taxonomy

A total of 14 spore species belonging to 11 genera have been identified in the investigated samples, together with three taxa identified to genus level. These results reveal the presence of abundant but relatively low diverse early land plant vegetation in Skåne during this time. Several spore species, such as *Gneudnaspora divellomedia* and *G. plicata*, *Dyadospora murusdensa* and *D. murusattenuata* and *Tetrahedraletes medinensis* occur in vast numbers throughout the samples and are also long-range species. *Ambitisporites avitus* and *A. dilutus* are also relatively common in most samples but not in such vast numbers as previously mentioned. A few species were also very rare and only occurred in one sample e.g. *Emphanisporites neglectus*, *Artemopyra radiata*, *Retusotriletes* sp., *Hispanaediscus* sp, *Hispanaediscus verrucatus*, *Cymbohilates* sp, and *Cymbohilates variabilis*. However, species such as *Ambitisporites parvus*, *Synorisporties* cf. *libycus* and *Apiculiretusispora? burgsvikensis* occur in several samples but in low numbers. There is further an occurrence of rugulate fungal spores in one sample.

6.2 Cryptospores and miospores

The abundance of miospores (trilete spores) increases relatively to cryptospores in the top of the section and the cryptospores, which are strongly dominating in the basal samples become less prominent towards the top. This is possibly related to the fact that the cryptospores are the more primitive forms of spores, and the plants producing them eventually died out in favour for more modern plants that produce miospores. This evolution might be reflected in the drillcore from Skåne. However, it might also reflect the preservation or taphonomic conditions as cryptospores have shown to be preserved most abundantly in terrestrial and near shore environments while miospores are more abundant in more distal marine sediments (Richardson 1996a). This would indicate that the environment was more near shore in the lower part of the section and more distal marine in the topmost part of the sequence. However that does not agree with the higher abundance of marine organisms in the lowermost part of the section, which in that case would indicate a more near shore environment because the cryptospores dominate. This favours the hypotheses that it is a reflection of the decrease of cryptospore producing plants due to evolution. However further investigation is necessary to solve the question.

6.3 Comparison to other assemblages

In comparison to other coeval assemblages, the spore assemblages of this study share most common species with assemblages from Gotland (Hagström 1997). The Gotland assemblage which is dated to middle Llandovery – late Ludlow (Hagström 1997) has 12 species in common with the assemblages of this study. The species *Apiculiretusispora*? *burgsvikensis* that was first described by Hagström (1997), occur in the Gotland material and is also present in the palynological associations of this study. The Gotland assemblage, however, show a more diverse palynoflora compared to the assemblages of this study as several species in the Gotland assemblage are not present in this one. On the other hand, there are also a few species present in this study that not occur in Hagströms material. One genus that does not occur in the late Silurian of Gotland is *Emphanisporites*, however only one specimen was found in the Skåne assemblage. All the species in this study except *Artemopyra radiata*, *Emphanisporites neglectus* and *Retusotriletes* sp. are common in Hagströms (1997) study from Gotland. There are very few studies made on coeval assemblages from Baltica and it is not surprising that the study from Gotland shows large similarities in species composition regarding the proximity to Skåne. The material from Gotland have few species in common with other coeval assemblages. Hagström (1997) argues that the difference in composition of the Gotland material compared to other assemblages may illustrate a separation of the flora from other floras in surrounding land areas. This might be true for the Skåne material as well. Other coeval assemblages that resembles the one in this study is an assemblage from Nova Scotia, Canada (Beck & Strother 2001) with eight species in common, the Midland Valley of Scotland (Wellman & Richardson 1993) with seven species in common and the Prauge Basin (Dufka 1995) with eight species in common. This means that the similarity on species level reaches approximately 50% between the Klinta BH 1 assemblages and the previously mentioned assemblages. It is mostly long ranging species e.g; *Gneundnaspora divellomedia*, *Ambitisporites avitus*, *A. dilutes* and *Hispanediscus verrucatus* that are in common with this study and also with studies outside Baltica.

During the late Silurian, a geographic differentia-

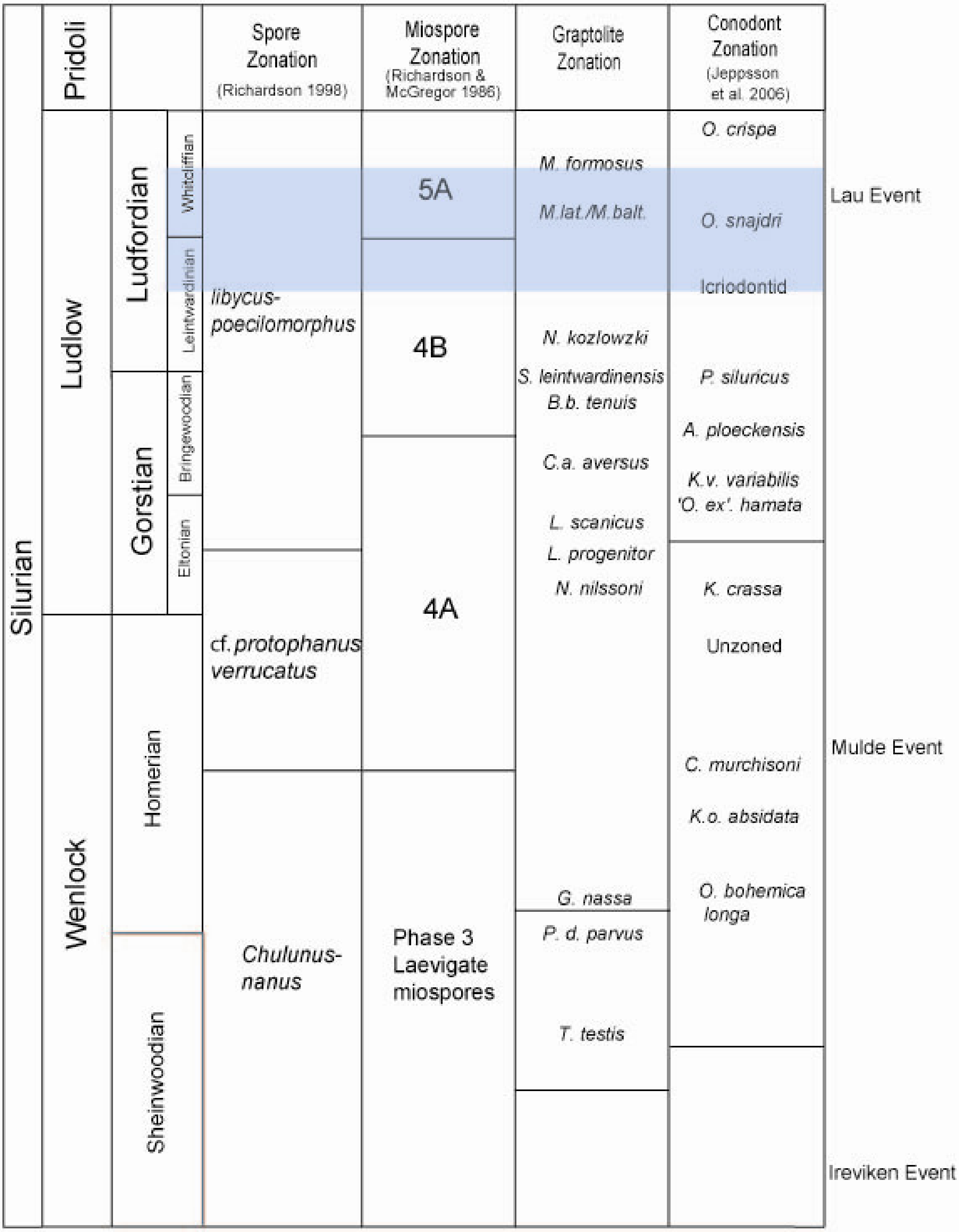

Figure 11. Correlation chart showing correlations between Spore zonation, Miospore zonation, Graptolite zonation and Conodont zonation. The blue square shows the interval coverd by this study. The three Silurian evnts are indicated.

tion in the morphology of fossil spores occurred and there are distinct differences in assemblages from North America compared to the ones from Gotland. This is possibly a consequence of the beginning of a biogeographical differentiation (Gray 1985) which could explain the differences in taxa-composition between this study and studies from other continents.

6.4 Depositional environment

The depositional environment is interpreted to be predominantly near shore marine to lagoonal intertidal based on the low, but regular occurrence of acritarchs together with the high relative abundance of spores through the main part of the drillcore. From 82.41 m to 93.34 m there is an almost total lack of spores. The marine organisms such as acritarchs, scolecodonts and chitinozoans are also missing. However there is a high relative abundance of wood in this interval. The interval is entirely dominated by wood remains and contains so few specimens of all the other groups that no statistically well supported interpretation is feasible, at this stage.

A possible explanation for the lack of spores and other organisms and the great abundance of wood may be; a highly oxidizing environment. This agrees well with the fact that the sediments from this interval are in places, red-coloured and contain dewatering structures, strongly corroded quartz grains and evaporative minerals (Wigforss-Lange pers. com.). All together indicating a high-tidal to supra-tidal environment. Thus, when the area dried out the organic material was oxidized and the woody material, being more resistant to oxidization, remained. Further, black woody particles (charcoal) that are more resistant than brown and black particles, are dominating in the deviant interval 82–94 m, especially in the sample 82.41 m. Below the interval, the particles are brown. Not only does this provide information of the depositional environment, but the presence of charcoal may also be indicative of late Silurian wildfires.

In a study made by Gray et al. (1974) Silurian palynomorphs from Gotland and Skåne in Sweden were investigated for an ecological analysis. The spores showed an inverse relationship to marine organisms such as acritarchs and chitinozoans; where spores were abundant, acritarchs and chitinozoans were rare and vice versa. This appears to correlate to environmental changes where spores are more abundant in shallower waters and acritarchs and chitinozoans in deeper waters. This pattern agrees well with the results from this study where spores and acritarchs shows an inverse relationship and consequently an increase in acritarchs (marine organisms) indicates deeper marine conditions. At some intervals the marine organisms increase in this study which indicates more marine conditions in the lower samples.

The plants responsible for the spore dispersal probably grew along distributary channels and their spores could spread by rivers and subsequently become concentrated in the near shore to offshore environments of the inner shelf. Richardson (1996b) argues that some spores can have been dispersed by the wind since some are below 25 µm. However most species ranges up to 60 µm and are thus too heavy for wind dispersal. Most spores in this study have a size over 30 µm and are most probably dispersed by water into the basin.

6.5 Spore stratigraphy

According to Richardsons (1996a) spore stratigraphy, the Skåne assemblage belongs to miospore subphase 4B–5A (Fig. 10) in the apiculate retusoid miospore phase and is of late Ludfordian age. In this study this phase is represented by *Apiculiretusispora*? *burgsvikensis*. However, this species is not confidently assigned to the *Apiculiretusispora* genus (see Hagström 1997).

In comparison to the spore zonation made by Richardson & McGregor (1986) this assemblage probably belongs to zone 4; *Synorisporites libycus*- ? *Lophozonotriletes poecilomorphus* Assemblage Zone. This zone stretches from Gorstian to Ludfordian. Three of the eight characteristic species were present in this study; *Synorisporites* c.f. *libycus* and *Emphanisporites neglectus* and *Hispanediscus verrucatus*. There is though some uncertainty to whether *Synorisporites* cf. *libycus* belongs to the species *libycus*. Zone number 4 is characterized by the first appearance of proximal radial muri on trilete spores (*Emphanisporites*), distal murornate sculpture and apiculate tetragonal tetrads. This zones also contains the beginning of apiculate sculpture (*Apiculiretusispora* ? *burgsvikensis*) on trilete spores and first appearance of foveolate sculpture. There is also a persistence of all nominal species in the previous zones. Zone 1; *Ambitisporites avitus*– *A. dilutus* Assemblage zones stretches from early and late Llandovery (Aeronian and early Telychian). From this zone this assemblages contain *Ambitisporites avitus*, *A. dilutus* and *Tetrahedraletes medinensis* from the characteristic species of the zone. Zone 2; *Archaeozonotriletes chulus* var. *chulus*– *A. chlus* var. *Nanus* Assemblage Zone from the late Llandovery to late Wenlock (Telychian to late Homerian) is represented by *A. avitus*, *A dilutus*, *Gneudnaspora divellomedia* and *Tetrahedraletes medinensis* of the characteristic species of this zone. Zone 3; ”*Emphanisporites*” cf. *Prtophanus*– cf. *Synorisporites verrucatus* Assemblage Zone from late Wenlock to early Ludlow (late Homerian to early Gorstian) is represented by *A. dilutus*, and *G. divellomedia* from this study. So, the presence of *Emphanisporites negelctus*, *Synorisporites* cf. *libycus*, *Hispanediscus verrucatus* and *Apiculiretusispora? burgsvikensis* together with the presence of several characteristic species from previous zones indicate that this assemblage belongs to the *Synorisporites libycus*- ?*Lophozonotriletes poecilomorphus* Assemblage Zone and is of Gorstian to Ludfordian age. Together with the miospore zonation which indicated that the assemblage belongs to miospore subphase 5A of late Ludfordian age. This supports a Ludfordian age for the spore assemblage from Skåne.

6.6 Correlation with the existing zonation of other fossil groups

As outlined in the previous section, the age determination for the studied interval is based on its fossil spores, and determined to a late Ludfordian age, encompassing the Leintwardian –Whitcliffian boundary (Fig. 11). This agrees well with previous studies of tentaculitids identified from the same drillcore (Larsson 1979). The miospore subphase 4B–5A coincides with the presence of the following tentaculitid species *Tentaculites hisingeri* and *Odessites portensis* of Larsson 1979.

Studies of other fossil groups such as conodonts (Jeppsson & Laufelt 1986), and chitinozoans (Grahn 1996), have been made on coeval, exposed sediments in Skåne and correlations have been made to the Klinta well 1 in Fig. 10. The studied spore assemblages make up the upper part of Zone 4B and the lower part of Zone 5A which corresponds to the conodont zones Icrodontid and *O. snajdri*, recognized from the quarry at Bjärsjölagård and from coeval sediments on Gotland (Jeppsson et al. 2006). It also correlates to the graptolite zone *M. latilobus/M. balticus* (Jeppsson et al. 2006).

An extensive study of the paleogeography of the Polychaetan family *Ramphoprionidae* has been made on sediments from the Bjärsjölagård Limestone Member of the Klinta Formation of Skåne and the following species were indentified in the studied interval, *Protarabellites rectangularis*, *P. staufferi*, *P. triangularis* and *Ramphoprion gotlandensis* (Eriksson 2002).

Extensive microfossil studies of coeval strata have been carried out on the island of Gotland, mainly on conodonts (Jeppsson et al. 2006 and references therein) and scolecodonts (Eriksson et al. 2004) but major correlation with areas outside Skåne is beyond the scope of this thesis.

6.7 Paleobotanical significance

The Skåne assemblage is important because it is one of the few studied palynological assemblages of the upper Silurian from Baltica. The lack of diversity (14 species and 11 genera) found in the sporomorph assemblage indicates that the flora from this period in Skåne comprised few taxa and was not diverse. The sporomorph assemblage also comprised a number of cosmopolite species. Since it's rare to find plant macrofossils from this time, spores are the best indicator of the terrestrial flora and its diversity. The similarities between this assemblage and the coeval assemblage from Gotland (Hagstöm 1997) suggest similarities in taxa between the rather close island of Gotland and Skåne from this time.

Some spores have previously been found in situ in the sporangia. For example *Ambitisporites* have been found in the sporangia of the rhyniophytoid homosporous plant *Cooksonia* (Richardson 1996b). It is also known that rhyniophytoids with indistinguishable sporangia can contain several different spore species (Fanning 1987). *Cooksonia pertoni* is for instance divided in three subspecies after its different spore species. *C. pertoni* subsp. *pertoni* is one of the subspeices of this plant and spreads the *Ambitisporites* spores (Richardson 1996b).

According to Richardson and McGregor (1986) the end of the *libycus-poecilomorphus* Zone correlates to the Floral Zone of Banks; (1980) *Cooksonia*. Wellman and Gray (2000) argues that the origin of trilete spores is probably a consequence of the rise of vascular plants (such as *Cooksonia*). The increase of trilete spores (miospores) in the samples in this study may be due to that the vascular plants started to compete with more primitive non-vascular cryptospore producing plants. It is known that in the earliest Devonian cryptospores decrease in spore assemblages and are only a minor part of the assemblages. Trilete spores however start to dominate in the assemblages. Cryptospores disappear altogether from the records in Lockhovian (Early Devonian) (Wellman & Gray 2000).

The presence of fungal spores and fungal remains in the samples, such as hyphae, suggest that fungus made up an important part of the late Silurian ecosystems, were the spore producing land plants grew in Skåne approximately 440 Ma. The occurrence of cuticle sheets and tubular structures that are interpreted to be remains of early land plants from this period (Wellman & Gray 2000) further suggests that land plants were thriving in the Silurian world.

9. Conclusions

- A palynological investigation carried out on Silurian drill core sediments from Skåne, Sweden reveal a well preserved palynological assemblage. 14 spore species belonging to 11 genera were identified. Additionally, 3 taxa were identified to genus level. The most common species in the assemblages is *Genudnaspora plicata.*
- Based on the spore content, the sediments have been dated to upper Ludlow (Ludfordian) which is equivalent to 420 Ma The assemblage belongs to Richardson's (1996b) miospore subphase 4B–5A of late Ludfordian age and the *Synorisporites libycus*-? *Lophozonotriletes poecilomorphus* Assemblage Zone of Gorstian to Ludfordian age.
- The studied spore assemblages further correlates to Graptolite Zone *M. latilobus/M. balticus* Zone and Conodont Zone *O.snajdri* and the occurrence of the tentaculitid species *Tentaculites hisingeri* and *Odessites portensis.* The relative abundance of spores varies through the sampled sediments. The assemblages are mainly dominated by spores from land plants

indicating near shore – intertidal environment. However, an interval characterized by a total lack of spores is interpreted to be a high-tidal to supra-tidal environment where organic materials were oxidized.

- The sporomorph assemblage from Skåne shows large similarities in species composition to coeval assemblages from Gotland.
- The trilete spores (miospores) increase in abundance in the higher parts of the section and this suggests a decrease in cryptospore producing plants which strongly dominate in the lower sections and is known to eventually die out in the early Devonian.
- The occurrence of cuticle sheets and tubular structures in the samples further evidence the presence of land plants in the upper Silurian.
- Occurrence of fungal spores and hyphea indicates that fungus was an important part of the Silurian ecosystems.
- The thermal alteration index based on the spores are –3 and indicates possible hydrocarbon presence .

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List of species:

Ambitisporites avitus Hoffmeister 1959– Fig. 9C–D.
Ambitisporites dilutus (Hoffmeister) Richardson & Lister 1969 – Fig. 9A–B.
Ambitisporties parvus Burgess & Richardson 1995 – Fig. 9E.
Artemopyra radiata Strother 1991 – Fig.8A.
Apiculiretusispora ? burgsvikensis Hagström 1997 – Plate 9I.
Cymbohilates variabilis Richardson 1996 – Fig. 7B, D.
Cymbohilates sp. – Fig. 8C.
Dyadospora murusattenuata (Strother & Traverse 1979) Burgess & Richardson 1991– Fig. 8N.
Dyadospora murusdensa (Strother & Traverse) Burgess & Richardson 1991– Fig. 8M.
Emphanisporites neglectus Vigran 1964– Fig. 9F.
Gneudnaspora divellomedia (Chibrickova) Balme 1988– Fig. 8G–H,J, Fig.10B–C,E.
Gneudnaspora plicata Burgess & Richardson 1995– Fig. 8I.
Hispanaediscus verrucatus (Cramer) Burgess & Richardson 1991– Fig. 8E.
Hispanaediscus sp. –Fig. 8F.
Retusotriletes sp.– Fig. 9H.
Synorisporites cf. *libycus* Richardson & Ioannides 1973 – Fig. 9G.
Tetrahedraletes medinensis (Strother & Traverse) Wellman & Richardson 1993 – Fig. 8K– L.

9. References

Balme, B., 1988: Miospores from Late Devonian (early Frasnian) strata, Carnarvon Basin, Western Australia. *Paleontographica*, *209*, 109–166.

Banks, H.P., 1980: *Floral assemblages in the Siluro–Devonian.* In D.L. Dilcher & T.N. Taylor (eds.): Biostratigraphy of fossil plants, sucessional and paleoecological analyses, 1–24. Dowden, Hutchinson and Ross Inc. Stroudsburg, Pennsylvania.

Beck, J.H., & Strother, P.K., 2001: Silurian Spores and Cryptospores from the Arisaig Group, Nova Scotia, Canada. *Palynology 25*, 127–177.

Bateman, R.M., Crane, P.R., DiMichele, W.A., Kenrick, P.R., Rowe, N.P., Speck, T. & Stein, W.E., 1998: Early Evolution of Land Plants: Phylogeny, Physiology and Ecology of the Primary Terrestrial Radiation. *Annual Review of Ecological System. 29*, 263– 292.

Burgess, N.D. & Richardson, J.B., 1991: Silurian cryptospores and miospores from the type Wenlock area, Shropshire, England. *Palaeontology 34*, 601–628.

Burgess, N.D. & Richardson, J.B., 1995: Late Wenlock to Early Pridoli cryptospores and miospores from south and southwest Wales, Great Britain. *Palaeonotographica 236*, 1–44.

Cherns, L., 1982: Palaeokarst, tidal erosion surfaces and stromatoites in the Silurian Eke Formation of Gotland, Sweden. *Sedimentology 29*, 819–833.

Cocks, L.R.M. & Scotese, C.R., 1991: The global biogeography of the Silurian period. Special Papers in *Palaeontology 44*, 109–122.

Cocks, L.R.M. & Torsvik, T.H., 2002: Earth geography from 500 to 400 million years ago: A faunal palaeomagnetic review. *Journal of the Geological. Society.* (London) *159*, 631–644.

Dufka, P., 1995: Upper Wenlock miospores and cryptospores derived from a Silurian volcanic island in the Prague Basin (Barrandian area, Bohemia). *Journal of Micropalaeontology 14*, 67–79.

Edwards, D., 1998: Climate signals in Palaeozoic land plants. *Philosophical Transactions of the Royal Society.* London. B *353*, 141–157.

Edwards, D. & Wellman, C. 2001: Plants Invade the Land. *In* Gensel, P.G. Edwards, D. (Eds). *Critical Moments & Perspectives in Paleobiology and*

Earth History. Columbia University Press, New York. 304 pp.

Eriksson, M., 2002: The palaeobiogeography of Silurian ramphoprionid polychaete annelids. *Palaeontology 45*, 985–996.

Eriksson, M.J. & Calner, M., 2008: A sequence stratigraphical model for the Late Ludfordian (Silurian) of Gotland, Sweden: implications for timing between changes in sea level, palaeoecology, and the global carbon cycle. *Facies* 54, 253–276.

Eriksson, M.E., Bergman, C.F. & Jeppsson, L., 2004: Silurian scolecodonts, *Review of Palaeobotany and Palynology 131*, 269– 300.

Fanning, U. 1987: *Late Silurian– Early Devonian plant assemblages in the Welsh Borderland*; Ph.D. thesis. University of Wales, Cardiff, 270 p., 20 pl. (Unpbulished.).

Grahn, Y, 1996: Upper Silurian (Upper Wenlock–Lower Pridoli) chitinozoa and biostratigraphy of Skåne, southern Sweden, *GFF 118*, 237–250.

Gray, J., 1985: The microfossil record of early land plants: advances in understanding of early terrestrialization, 1970–1984. *Philosophical Transactions of the Royal Society* of London, Series B, *309*, 167–195.

Gray, J., Laufeld, S. & Boucot, A.J., 1974: Silurian Trilete Spores and Spore Tetrads from Gotland: Their implications for Land Plant Evoloution. *Science 185*, 260–263.

Gray, J., Boucot, A.J., Grahn, Y. & Himes, G., 1992: A new record of early Silurian land plant spores from the Paraná Basin, Paraguay (Malvinokaffric Realm). *Geological Magazine. 129*, 741–752.

Guilford, W.J, Schneider, D.M., Labovitz, J., Opella, S.J.:1988 High-Resolution Solid-State C–13 NMR-Spectroscopy of Sporopollenins from Different Plant Taxa. *Plant Physiology 86*, 134–136.

Hagström, J., 1997: Land-derived palynomorphs from the Silurian of Gotland, Sweden. *GFF 119*, 301–316.

Hoffmeister, W.S., 1959: Lower Silurian plant spores from Libya. *Micropaleontology 5*, 331–334.

Jeppsson, L. & Laufeld, S., 1986: The Late Silurian Öved-Ramsåsa Group in Skåne, southern Sweden. *Sveriges Geologiska Undersökning*, Serie Ca *58*, 1–45.

Jeppsson, L., Aldridge, R. J., & Dorning. K. J., 1995: Wenlock (Silurian) oceanic episodes and events. *Journal of the Geological Society*, London *152*, 487–498.

Jeppsson, L., Eriksson, M.E., & Calner, M. 2006: A latest Llandovery to latest Ludlow high– resolution biostratigraphy based on the Silurian of Gotland– a summary. *GFF 128*, 109–114.

Larsson, K., 1979: Silurian tentaculitids from Gotland and Scania. *Fossils and Strata 11*, 1–180.

Lehnert, O., Frýda, J., Buggisch, W., Munnecke, A., Nützel, A., Kriz, J. & Manda, S., 2006: δ^{13}C records across the late Silurian Lau event: New data from middle palaeo-latitudes of northern peri-Gondwana (Prague Basin, Czech Republic). *Palaeogeography, Palaeoclimatology, Palaeoecology 245*, 227–244.

McGregor, D.C., 1961: Spores with proximal radial pattern from the Devonian of Canada. *Geological Survey of Canada Bulletin 76*, 1–11.

McGregor, D.C. & Narbonne, G.M. 1978: Upper Silurian trilete spores and other microfossils from the Read Bay Formaion, Cornwallis Island, Canadian Arctic. *Canadian Journal of Earth Sciences 15*, 1292–1303.

Moore, G.T., Jacobson, S.R., Ross, C.A. & Hayashida, D.N., 1994: A paleoclimate simulation of the Wenlockian (Late Early Silurian) world using a general circulation model with implications for early land plant paleoecology. *Palaeogeography, Palaeoclimatology, Palaeoecology 110*, 115–144.

Munnecke, A., Samtleben, C. & Bickert, T., 2003: The Ireviken Event in the lower Silurian of Gotland, Sweden – relation to similar Palaeozoic and Proterozoic events. *Palaeogeography, Palaeoclimatology, Palaeoecology 195*, 99– 124.

Pearson, D.L., 1984: *Pollen/spore colour 'standard'. Phillips Petroleum Company Exploration Projects Section* (reproduced in Traverse, A., 1988. Palaeopalynology, Plate 1. Unwin Hyman, Boston).

Potonié, H., 1893: Die Flora des Rodiegen von Thüringen. *Abhandlungen der Königlich Preussischen Geologischen Landes-Anstalt 9*, 1–298.

Potonié, R. & Kremp, G., 1954: Die Gattugnen der paläozoischen Sporae dispersae und ihre Stratigraphie. *Geologisches Jahrbuch 69*, 111–194.

Raymond, A., Gensel, P. & Stein, W.E., 2006: Phytogeography of Late Silurian macrofloras. *Review of Palaeobotany and Palynology 142*, 165–192.

Richardson, J.B., 1965: Middle Old Red Sandstone spore assemblages from the Orcadian Basin, northeast Scotland. *Palaeontology 7*, 559–605.

Richardson, J.B., 1988: *Late Ordovician and Early Silurian cryptospores and miospores from northeast Libya. In* A. El-Arnaut, B. Owens & B. Thusu (eds.): *Subsurface palynostratigraphy of northeast Libya*, 89–109. Garyounis University Publications, Bengahzi, Libya.

Richardson, J.B., 1996a: Taxonomy and classification of some new early Devonian cryptospores from Britain. In C.J. Cleal (eds.): *Studies on early land plant spores from Britain. Special Papers in Paleontology 55*, 7–40.

Richardson, J.B., 1996b: *In Palynology: principles and applications*, vol. 2, Applications J. Jansounius & D.C. McGregor (eds.) pp. 555–574. Salt Lake City, UT: American Association of Stratigraphic Palynologists Foundation. Publishers Press.

Richardson, J.B., 2007: Cryptospores and miospores in the Lower Old Red Sandstone of the Anglo-Welsh Basin. *Bulletin of Geosciences 82*, 355–364.

Richardson, J.B. & Edwards, D., 1989: *Sporomorphs and plant megafossils. In* A global standard for the Silurian System C.H. Holland & M.G. Bassett (eds.): , 216–226. National Museum of Wales, Cardiff, Geological Series 9.

Richardson, J.B. & Ioannides, N.S., 1973: Silurian palynomorphs from the Tanezzuft and Acacus formations, Tripolitana, North Africa. *Micropalaeontology 19*, 257–307.

Richardson, J.B. & Lister, T.R., 1969: Upper Silurian and Lower Devonian spore assemblages from the Welsh Borderland and South Wales. *Palaeontology 12*, 201–252.

Richardson, J.B. & McGregor, D.C., 1986: Silurian and Devonian spore zones of the Old Red Sandstone continent and adjacent regions. *Geological Survey of Canada, Bulletin 364*. 1–73.

Richardson, J.B., Ford, J.H. & Parker., 1984: Miospores, correlation and age of some Scottish Lower Old Red sandstone sediments from the Strathmore region (Fife and Angus). *Journal of Micropalaeontology 3*, 109–124.

Scherwood-Pike, M.A. & Gray, J., 1985: Silurian fungal remains: probable records of the Class Ascomycetes. *Lethaia 18*, 1–20.

Scotese, C.R., PALEOMAP project. http://www.scotese.com/

Steemans, P., 2000: Miospore evolution from the Ordovician to the Silurian *Review of Palaeobotany and Palynology 113*, 189.

Steemans, P., le Hérissé, A. & Bozdogan, N., 1996: Ordovician and Silurian cryptospores and miospores from southeastern Turkey. *Review of Palaeobotany and Palynology 93*, 35–76.

Steemans, P., Le Hérissé, A., Melvin, J., Miller, M.A., Paris, F., Verniers, J. & Wellman, C.H., 2009: Origin and Radiation of the Earliest Vascular Land Plants. *Science 324*, 353.

Streel, M., 1964: Une association du Givéetian inférieur de la Vesdre à Goé (Belgique). *Annales de la Société Géologique de Belgique 87*, 1–30.

Stricanne, L., Munnecke, A. & Pross, J., 2005: Assessing mechanisms of environmental change: Palynological signals across the Late Ludlow (Silurian) positive isotope excursion (^{13}C, ^{18}O) on Gotland, Sweden. *Palaeogeography, Palaeoclimatology, Palaeoecology 230*, 1–31.

Strother, P.K., 1991: A classification for the cryptospores. *Palynology 15*, 4–20.

Strother, P.K. 2000: Phanerozoic Terrestrial Ecosystems. Gastaldo, R.A., DiMichele, W.A. (eds.) *In Palaeontological Society Papers*, No. 6, Pittsburgh, PA, pp. 3–20.

Strother, P.K. & Traverse, A., 1979: Plant microfossils from Llandoverian and Wenlockian rocks of Pennsylvania. *Palynology 3*, 1–22.

Traverse, A., 1988: *Paleopalynology*. Unwin Hyman, Boston. 600 pp.

Traverse, A., 2007: *Paleopalynology*. Second Edition. Springer, 813 pp.

Vavrdova, M., 1989: New acritarchs and miospores from the late Ordovician of Hlásná Treban, Czchoslovakia. *Cas. Mineral. Geol. 34*, 403–420.

Vigran, J., 1964: Spores from Devonian deposits, Mimerdalen, Spitsbergen. *Norsk Polarinst. 132*, 1–32.

Wellman, C.H., 1993a: A land plant microfossil assemblage of Mid Silurian age from the Stonehaven Group, Scotland. Journal of *Micropalaeontology 12*, 47–66.

Wellman, C.H., 1993b: A Lower Devonian sporomorph assemblage from the Midland Valley of Scotland. *Trans. R. Soc. Edinburgh, Earth Sci. 84*, 117–136.

Wellman, C.H. & Gray, J., 2000: The microfossil record of early land plants. *Philosophical Transactions of the Royal Society. London.* B 355, 717–732.

Wellman, C.H. & Richardson, J.B., 1993: Terrestrial plant microfossils from Silurian inliers of the Midland Valley of Scotland. *Palaeontology 36*, 155–193.

Wellman, C.H. & Osterloff, U., 2003: Fragments of the earliest land plants. *Nature 425*, 282–285.

Wigforss-Lange, J., 1999: Carbon isotope 13C enrichment in Upper Silurian (Whitcliffian) marine calcareous rocks in Scania, Sweden. *GFF 121*, 273 279.

Wigforss-Lange, J., 2007: Tidal facies in the Upper Silurian Öved Ramsåsa Group of Scania, Sweden: Linkages of radial and cerebroid ooids and evaporite tracers to subtidal lagoonal environment. *GFF 129*, 8–15.

Wenzel, B., 2000: Differential preservation of primary isotopic signatures in Silurian brachiopods from Northern Europe. *Journal of Sedimentary Resarch 70*, 194–209.

Ziegler, A.M., Hansen, K.S., Johnson, M.E., Kelly, M.A., Scotese, C.R. & Van Der Voo, R., 1977: Silurian continental distributions, palaeogeography, climatology and biogeography. *Tectonophysics 40*, 13–51.

APPENDIX 1 (Sample number and spore contents)
Sample number: 1, R.2077-1/COR
80.12 m
Counted spores*:* 703
Spore species found of 150 spores:
Ambitisporites avitus: 35
Ambitisporites dilutus: 1
Gneudnaspora divellomedia: 67
Synorisporties cf. *libycus*: 11
Apiculiretusispora ?burgsvikensis: 1
Tetrahedraletes medinensis: 3
Gneudnaspora plicata: 19
Hispanaediscus sp.: 1
Rugulated fungal spores: 12

Sample number: 2, R-2077-2/COR
82.41 m
Counted spores: 4

Sample number: 3, R-2077-3/COR
85.00 m
Counted spores: 0

Sample number: 4, R.2077-4/COR
87.88 m
Counted spores: 0

Sample number: 5, R-2077-5/COR
89.38 m
Counted spores: 2

Sample number: 6, R-2077-6/COR
90.74 m
Counted spores: 0

Sample number: 7, R2077-7/COR
93.34 m
Counted spores: 15

Sample number: 8, R2077-8/COR
94.67 m
Counted spores: 29

Sample number: 9. 2077-9/COR
96.02 m
Counted spores: 1297
Spore species found of 150 spores:
Ambitisporites avitus: 20
Ambitisporites dilutus: 4
Apiculiretusispora? burgsvikensis: 1
Dyadospora murusdensa: 1
Gneudnaspora divellomedia: 40
Gneudnaspora plicata: 75
Synorisporites cf. *libycus*: 3
Tetrahedraletes medinensis: 14

Sample number: 10, R2077-10/COR
99.79 m
Counted spores: 60

Sample number: 11, R2077-11/COR
100.45 m
Counted spores: 463
Spore species found of 150 spores:
Ambitisporites avitus: 31
Ambitisporites dilutus: 5
Ambitisporites parvus: 1
Dyadospora murusdensa: 19
Dyadospora murusattenutat: 6
Gneundaspora divellomedia: 15
Genudnaspora plicata: 61
Tetrahedraletes medinensis: 12

Sample number: 12, R2077-12/COR
101.95
Counted spores: 2226
Spore species found of 150 spores:
Ambitisporites avitus: 35
Apiculiretusispora? burgsvikensis: 1
Dyadospora murusdensa: 25
Gneudnaspora divellomedia: 18
Gneudnaspora plicata: 60
Tetrahedraletes medinensis: 6

Sample number: 13, R2077-13/COR
103.58 m
Counted spores: 2933
Spore species found of 150 spores:
Ambitisporites avitus: 21
Ambitisporites dilutus: 5
Cymbohilates variabilis: 1
Dyadospora murusdensa: 21
Dyadospora murusattenuata: 1
Gneudnaspora divellomedia: 59
Gneudnaspora plicata: 36
Hispanaediscus verrucatus: 2
Retusotriletes sp. : 1
Tetrahedraletes medinensis: 3

Sample number: 14, R2077-14/COR
107.7 m
Counted spores: 1670
Spore species found of 150 spores:
Ambitisporites avitus: 6
Ambitisporites dilutus: 5
Dyadospora murusdensa: 6
Gneudnaspora divellomedia: 53
Gneudnaspora plicata: 75
Tetrahedraletes medinensis: 5

Sample number: 15, R2077-15/COR
112.28 m
Counted spores: 2508
Ambitisporites avitus: 14
Ambitisporites dilutus: 18
Apiculiretusispora? burgsvikensis: 1
Dyadsopora murusdensa: 8
Dyadospora murusattenutat: 6
Gneudnapsora divellomedia: 77
Gneudnapora plicata: 34

Tetrahedraletes medinensis: 6

Sample number: 16, R2077-16/COR
116.28 m
Counted spores: 793
Spore species found of 150 spores:
Ambitisporites avitus: 5
Ambitisporites dilutus: 8
Cymbohilates sp. : 1
Dyadospora murusdensa: 12
Dyadospora murusattenutat: 2
Gneudnaspora divellomedia: 47
Gneudnaspora plicata: 63
Tetrahedraletes medinensis: 12

Sample number: 17, R2077-17/COR
117.42 m
Counted spores: 881
Spore species found of 150 spores:
Ambitisporites avitus: 2
Ambitisporites dilutus: 3
Cymbohilates sp.: 3
Dyadospora murusdensa: 82
Gneudnaspora divellomedia: 10
Gneudnaspora plicata: 60
Tetrahedraletes medinensis: 3

Sample number: 18, R2077-18/COR
120.64 m
Counted spores: 214

Sample number: 19, R2077-19/COR
122.96 m
Counted spores: 671
Spore species found of 150 spores:
Ambitisporites avitus: 2
Ambitisporites dilutus: 1
Ambitisporites parvus: 1
Apiculiretusispora ? burgsvikensis: 1
Cymbohailites variabilis: 1
Dyadospora murusdensa: 22
Dyadospora murusattentuat: 78
Gneudnaspora divellomedia: 5
Gneudnaspora plicata: 35
Tetrahedraletes medinensis: 5

Sample number: 20, R2077-20/COR
128.42 m
Counted spores: 34

Sample number: 21, R2077-21/COR
129.07 m
Counted spores: 208

Sample number: 22, R2077-22/COR
137.17 m
Counted spores: 169

Sample number: 23, R2077-23/COR
138.83 m
Counted spores: 943
Spore species found of 150 spores:
Ambitisporites avitus: 9
Ambitisporites dilutus: 3
Ambitisporites parvus: 1
Dyadospora murusdensa: 63
Dyadospora murusuttentuat: 11
Gneudnaspora divellomedia: 31
Genudnaspora plicata: 23
Tetrahedraletes medinensis: 10

Sample number: 24, R2077-24/COR
143.33 m
Counted spores: 936
Spore species found of 150 spores:
Ambitisporites avitus: 7
Ambitisporites dilutus: 2
Ambitisporites parvus: 1
Dyadospora murusdensa: 26
Gneudnaspora divellomedia: 23
Gneudnaspora plicata: 101

Sample number: 25, R2077-25/COR
146.51 m
Counted spores: 36

Sample number: 26, R2077-26/COR
151.76 m
Counted spores: 1235
Spore species found of 150 spores:
Ambitisporites avitus: 1
Ambitisporites parvus: 2
Artemopyra radiata: 1
Apiculiretusispora? burgsvikensis: 1
Dyadospora murusdensa: 24
Dyadospora murusattenuata: 1
Emphanisporites neglectus: 1
Gneudnaspora divellomedia: 20
Gneudnaspora plicata: 116

Sample number: 27, R2077-27/COR
153.41 m
Counted spores: 1706
Spore species found of 150 spores:
Ambitisporites dilutus: 1
Ambitisporites parvus: 2
Dyadospora murusdensa: 53
Dyadospora murusattentuat: 6
Gneudnaspora divellomedia: 22
Gneudnaspora plicata: 65
Tetrahedraletes medinensis: 5

Sample number: 28, R2077-28/COR
156.37 m
Counted spores: 1611
Spore species found of 151 spores:
Dyadospora murusdensa: 2
Dyadospora murusattentuat: 32
Gneudnaspora divellomedia: 39
Gneudnaspora plicata: 77

APPENDIX 2. Percentage of spore species in the samples from Klinta 1 well.

TAXA/ Sample level	**80.12**	**96.02**	**100.45**	**101.95**	**103.58**	**107.71**	**112.28**	**116.28**	**117.42**	**122.96**	**138.83**	**143.33**	**151.76**	**153.41**	**156.37**
MIOSPORES															
Ambitisporites avitus	23.3	12.7	20.7	23.3	14.0	4.0	8.6	3.3	1.2	1.3	6.0	4.4	0.6		
Ambitisporites dilitus	0.7	2.5	3.3		3.3	3.3	11.0	5.3	1.8	0.7	2.0	1.3		0.6	
Ambitisporites parvus			0.7							0.7	0.7	0.6	1.2	1.3	
Apiculiretusispora ? burgsvikensis	0.7	0.6		4.0				0.7		0.7			0.6		
Emphanisporites neg-													0.6		
Retusotriletes sp.					0.7										
Synorisporites cf. liby-	7.3	1.9													
Total % Miospores	32.0	17.7	24.7	27.3	18.0	7.3	19.6	9.3	3.1	3.3	8.6	6.3	3.0	1.9	
CRYPYOSPORES															
Artemopyra radiata													0.6		
Cymbohilates sp.								0.7	1.8						
Cymboilates variablis					0.7					0.7					
Dyadospora murusattenutat			4.0		0.7		3.7	1.3		51.7	7.3		0.6	3.9	21.3
Dyadospora murusden-		0.6	12.7	16.7	14.0	4.0	4.9	7.9	50.3	14.6	41.7	16.3	14.4	34.4	1.3
Gneudnaspora divellomedia	44.7	25.3	10.0	12.0	39.3	35.3	47.2	31.1	6.1	3.3	20.5	14.4	12.0	14.3	26.0
Gneudnaspora plicata	12.7	47.5	40.7	40.0	24.0	50.0	20.9	41.7	36.8	23.2	15.2	63.1	69.5	42.2	51.3
Hispanediscus sp.	0.7														
Hispanediscus verruca-					1.3										
Tetrahedraletes medinensis	2.0	8.9	8.0	4.0	2.0	3.3	3.7	7.9	1.8	3.3	6.6			3.2	
Total % Cryptospores	60.0	82.3	75.3	72.7	82.0	92.7	80.4	90.7	96.9	96.7	91.4	93.8	97.0	98.1	100.0
Fungal spores	8.0														

APPENDIX 3. Percentage of the sample contents in Klinta 1 well.

Drill core BH-1 (m) /%	Spore	Acritarch	Fungi	Scolecodont	Wood	Chitinozoans
80.12	82.2	3.6	0.5	0.4	12.5	0.8
82.41	0.4	0.1	0.1	0.0	99.5	0.0
85	0.0	4.3	0.0	0.0	95.7	0.0
87.88	0.0	0.0	0.0	0.0	100.0	0.0
89.38	2.1	0.0	0.0	0.0	97.9	0.0
90.74	5.4	0.0	5.4	0.0	89.2	0.0
93.34	5.2	0.7	0.0	0.0	94.1	0.0
94.67	21.2	15.3	2.2	0.0	61.3	0.0
96.02	79.3	1.7	0.4	0.1	18.5	0.0
99.79	8.4	4.7	0.7	0.0	86.2	0.0
100.45	99.4	0.6	0.0	0.0	0.0	0.0
101.95	91.5	0.3	6.8	0.0	1.4	0.0
103.58	98.9	0.2	0.2	0.1	0.6	0.0
107.71	97.2	0.9	0.1	0.3	1.4	0.1
112.28	99.0	0.4	0.1	0.1	0.3	0.1
116.28	89.3	8.4	0.0	1.0	0.6	0.7
117.42	90.4	7.2	0.5	0.5	1.4	0.0
120.64	89.5	7.9	0.4	0.0	2.1	0.0
122.96	97.5	1.3	0.1	0.0	0.9	0.1
128.42	53.1	21.9	1.6	0.0	20.3	3.1
129.07	69.8	2.7	0.3	0.0	25.2	2.0
137.17	83.7	5.9	0.5	0.0	8.9	1.0
138.83	86.2	2.8	0.1	0.1	7.0	3.7
143.33	82.0	14.4	0.0	0.0	0.2	3.5
146.51	73.5	16.3	2.0	0.0	8.2	0.0
151.76	95.7	3.9	0.2	0.0	0.2	0.0
153.41	95.1	1.1	0.0	0.2	1.7	1.8
156.37	93.8	5.1	0.0	0.1	0.8	0.2

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